3.8 MODELING OF SHORT-TERM EMISSION EXCURSIONS

The future case modeling discussed earlier assumed limited temporal variability in the emissions from industrial sources; only electric utility emissions maintained the variability built into the base case. Other emission sources were treated as having only the variability reported in the point source database, which, for the vast majority of point sources, amounts to constant emissions every hour of every day. But it is certain that point source emissions will exhibit significant temporal variability in the future. Non-routine variable emissions that may result from emissions events, start-up, shutdown or maintenance activities, are known to cause, or at least exacerbate, ozone exceedances under certain circumstances, so a control strategy must accommodate the possibility of such occurrences.

The HARC sponsored an extensive research project, noted as Project H-13, designed to characterize temporal emissions variability, develop methods to model this variability, and finally to assess the effects of variability on peak ozone concentrations (Allen, 2004). The work, led by Drs. David Allen of the University of Texas at Austin and Harvey Jeffries of the University of North Carolina, provided information essential to the development of a short-term emission limitation designed to avoid violations of the ozone NAAQS. The executive summary of the Project H-13 final report is provided below. The full report is provided in Appendix I.

> The Houston-Galveston area (HGA) is designated as a severe ozone non-attainment region, and the State of Texas is charged with developing a State Implementation Plan (SIP) for reducing emissions that lead to ozone formation. A first step in developing the SIP is to characterize and quantify the emissions that lead to high ozone concentrations. In the HGA, developing inventories of emissions that lead to high ozone concentrations is more complicated than in many other urban areas because of the extensive industrial operations in the region. Emissions from industrial facilities (point sources) are generally assumed, for SIP development purposes, to be continuous and at a nearly constant level. Emissions from Electricity Generating Units (EGUs) are the exception, and the State of Texas, and most other regions of the United States, use continuously collected data on emissions to characterize the role of EGUs in ozone formation. For petroleum refineries, chemical manufacturing facilities, and other industrial operations (non-EGUs), however, SIP analyses generally assume emissions are constant and continuous. This assumption is made because many non-EGUs operate 24 hours per day, 7 days per week, and their material throughput is nearly constant.
>
> Recent evidence, from a variety of sources, demonstrates that while some types of emissions of volatile organic compounds from non-EGU point sources are constant, others are not. The evidence includes emission event reports, air pollutant measurements made by aircraft, air pollutant measurements made by ground monitors, and industrial process measurements. Daily emissions from a single facility can vary from annual average emissions by a factor of 10-1000. Variations of this magnitude at any single facility typically occur only a few times per year, but because there are so many facilities in the HGA, on many days, there is likely to be a facility experiencing significant emission variability.
>
> Air quality measurements taken in recent field studies have also found evidence of localized regions with elevated concentrations of highly reactive volatile organic compounds (HRVOC). These regions with elevated HRVOC concentrations are frequently associated with very rapid ozone formation, leading to exceedances of the ozone air quality standard.

This report documents the evidence for HRVOC emission variability from non-EGU point sources, characterizes the nature of the variability and assesses the impact of variability on ozone formation processes in the HGA. The analyses presented in the report are summarized in a series of Findings.

Finding 1: Variability in HRVOC emissions from point sources is significant and is due to both variability in continuous emissions and discrete emission events[1]. *Roughly 3 times per month in 2003, reported emission events caused single facilities to have HRVOC emissions that were greater than 10,000 lb/hr (the total annual average emissions of HRVOCs, from all industrial point sources in the Houston-Galveston region is approximately 5,000 - 10,000 lb/hr). Roughly 3 times per week in 2003, reported emission events caused single facilities to have HRVOC emissions that were greater than 1,000 lb/hr. Roughly once a day in 2003, reported emission events caused single facilities to have HRVOC emissions that were greater than 100 lb/hr. Variability in continuous emissions is more difficult to quantify than emission variability due to reported emission events, but preliminary modeling indicates that variations in continuous (as opposed to discrete) emissions could cause emissions of total VOCs, averaged over areas larger than 100 km2, to vary by 5-10 percent.*

2-3 times per month HRVOC emissions variability > 10,000 lb/hr
2-3 times per week HRVOC emissions variability > 1,000 lb/hr
daily HRVOC emissions variability > 100 lb/hr

The impact of emission variability on ozone formation can take multiple forms. If the emission variability is large enough, and the meteorological conditions are sufficiently ozone conducive, the variability in emissions may be sufficient to cause an exceedance of the National Ambient Air Quality Standard (NAAQS) for ozone (concentrations averaged over 1-hour) that would not have occurred in the absence of the emission event. Documentation, from the Texas Commission on Environmental Quality (TCEQ), is provided in the report for a 6700 pound release of ethylene that caused ozone NAAQS exceedances at multiple monitors.

As noted in Finding 1, however, very large variations in emissions are less common than smaller variations in emissions. While very large variations in emissions might lead to ozone NAAQS exceedances directly, more frequent, smaller variations in emissions have the potential to marginally increase the magnitude of ozone concentrations. If the HRVOC emission variability occurs at critical times and locations, it can marginally increase the peak ozone concentration that might be expected in the Houston-Galveston area. Air quality modeling analyses were performed to assess the changes in peak, region-wide ozone concentrations that might be expected from HRVOC emission variability in the range of 100-5000 lb/hr.

---

[1]Reportable emission events are defined by Texas Administrative Code (TAC) Title 30 Chapter 101. Section 101.1, paragraph (83) defines a reportable emissions event as "Any emissions event which, in any 24-hour period, results in an unauthorized emission equal to or in excess of the reportable quantity…" The reportable quantity for HRVOCs is 100 lb. Emission variability, either discrete, or routine, may not in all cases result in a reportable emission event.

Finding 2: HRVOC emission variability in the range of 100-1000 lb/hr, which has been reported daily in the Houston-Galveston area, can increase peak, region-wide ozone concentrations, if the emission variability occurs in regions upwind of the location of the peak, region-wide ozone concentration. *The magnitude of the increase in ozone concentration depends on the location of the emission variability, the time of day when the emission variability occurs and the magnitude of the non-variable ozone precursor emissions. At the most sensitive locations, at the most sensitive times of day, releases over approximately a two to three hour period can lead to increases of 2-3 ppb in peak ozone concentration per 1000 lb of additional HRVOC emissions. This sensitivity may increase as non-variable HRVOC emissions decrease and* NO_X *emissions increase.*

Finding 1 suggests that HRVOC emission variability in the range of 100 to 1000 pounds per hour can be expected daily, at some time and some location in the Houston-Galveston area. Finding 2 suggests that if the emission variability occurs at a sensitive time and a sensitive location, that peak ozone concentration could be increased by 2-3 ppb for every 1000 lb of HRVOC emissions released. In order to link these two findings, it was necessary to assess how frequently emission variability might occur at sensitive times and sensitive locations.

The bases for the frequency analysis were a TCEQ database on event emissions, described in the report, and meteorological assessment of the frequency of ozone-conducive conditions. The frequency analysis suggests that, if the emission variability is not large enough to directly cause an ozone exceedance, then the probability that additional emissions will occur at the right time and at the right location to marginally enhance ozone peak concentration is small. The exact probability has significant uncertainty, but is most likely of order 1 in 20 to 1 in 200. Stated differently, only 1 in 20 to 1 in 200 randomly selected instances of emission variability is likely to be at the right time and in the right location to influence peak ozone concentration. However, because the regulatory goal is not to exceed the national ambient air quality standard for ozone more than once per year, even if the probability of an event being in the right place at the right time is 1 in 100, the frequency analysis documented in this report shows that emission variability of roughly 1000 lb/hr should be expected upwind of peak, region wide ozone concentrations.

This would suggest that, if no actions were taken to reduce emission variability, it would be necessary to plan for an event of 1000 pounds in an attainment demonstration, at a location that would influence peak ozone concentrations. If actions are taken to reduce emission variability, however, the magnitude of the emission variability that should be expected upwind of peak, region wide ozone concentrations, could be decreased.

Finding 3: Based on current data, emission variability of roughly 1000 lb/hr should be expected in the regions upwind of peak, region wide ozone concentration at least once per year in the Houston-Galveston area. *This finding is based on estimates of the frequency of ozone conducive conditions and the frequency and magnitude of HRVOC emission events reported through a TCEQ database. This expected value could potentially be decreased by imposing short term limits on HRVOC emission variability.*

3.9 WEIGHT-OF-EVIDENCE (WoE) ARGUMENTS

The WoE arguments discussed in this section coupled with the results presented in the previous two sections constitute a demonstration that the HGB area will reach attainment of the 1-hour ozone standard by 2007. First, August 31, the day showing the largest modeled future ozone concentrations, is discussed. This day is particularly resistant to controls, but it represents a meteorological regime that is extremely unusual and is unlikely to recur for many years. Next, additional reductions that were not modeled but are expected to occur prior to the attainment year are discussed. These reductions should reduce peak ozone concentrations substantially beyond those modeled for CS-08. A series of comprehensive ozone metrics showing the overall breadth of the benefits expected to accrue from CS-08 is provided. Finally, analyses of ambient monitoring data highlighting the observed trends in modeled ozone concentrations is included.

Because the differences between CS-08 and CS-06a were relatively minor, some parts of the WoE were not modified to reflect the new future control case. All conclusions reported for CS-06a remain valid for CS-08 because of the similarity between the two.

3.9.1 August 31

Modeling analysis to determine why August 31 is the only day that is not responsive enough to the control strategies.

The August 25 - September 6, 2000, ozone episode was modeled in support of the SIP revision. August 31 is the only day during this episode that is not reasonably responsive to the control strategies. Figure 3.9-1, *Modeled Peak Ozone Concentrations for Base5b and CS-08*, shows peak modeled ozone concentrations in the HGB area for the base case and future 2007control strategy run (CS-08). Peak ozone on all days except August 31 is below or within a few ppb of the 1-hour ozone standard of 125 ppb.

The second half of the ozone episode (August 30 - September 6, 2000) recorded all-time record high temperatures in Southeast and East Texas. The unusually hot weather may have been a contributing factor to the high ozone. High temperatures affect the magnitude of biogenic emissions, evaporative emissions of gasoline, and power plant emissions due to higher demands for electricity. High temperatures can also affect the rates of ozone-forming reactions. The hot weather was accompanied on some days by strong morning westerly winds, which were unusual as well. The purpose of this analysis is to determine why August 31 is the most difficult day for which to model attainment, and to assess whether it should be used as the controlling day for the 1-hour ozone attainment demonstration.

3.9.1.1 Climatological Frequency of August 30 - September 5 Conditions

Five days during the August 30 - September 5, 2000, period recorded temperatures greater than or equal to 104°F, including August 31. Table 3.9-1, *Peak Temperatures Observed at Houston Hobby Airport During the TexAQS 2000 Ozone Episode,* shows the peak temperature for each day of the episode. Figure 3.9-2, *Maximum Observed Temperatures at Houston Hobby, August 1 - Sept 30, 2000,* shows the maximum temperatures observed at Houston Hobby airport from August 1 - September 30, 2000 (J. Nielsen-Gammon, 2004, personal communication).

Figure 3.9-1: Modeled Peak Ozone Concentrations for Base 5b and CS-08

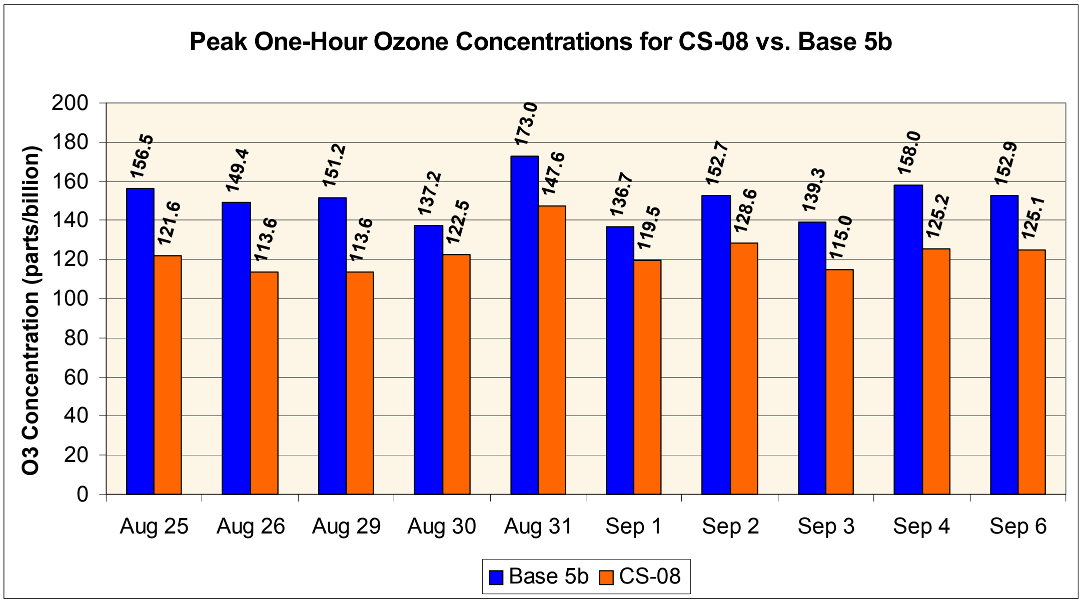


Table 3.9-1: Peak Temperatures Observed at Houston Hobby Airport During the TexAQS 2000 Ozone Episode	
22-August	90
23-August	89
24-August	92
25-August	93
26-August	94
27-August	94
28-August	97
29-August	98
30-August	102
31-August	104
1-September	104
2-September	104
3-September	103
4-September	108
5-September	107
6-September	94

Figure 3.9-2: Maximum Observed Temperatures at Houston Hobby, August 1-September 30, 2000

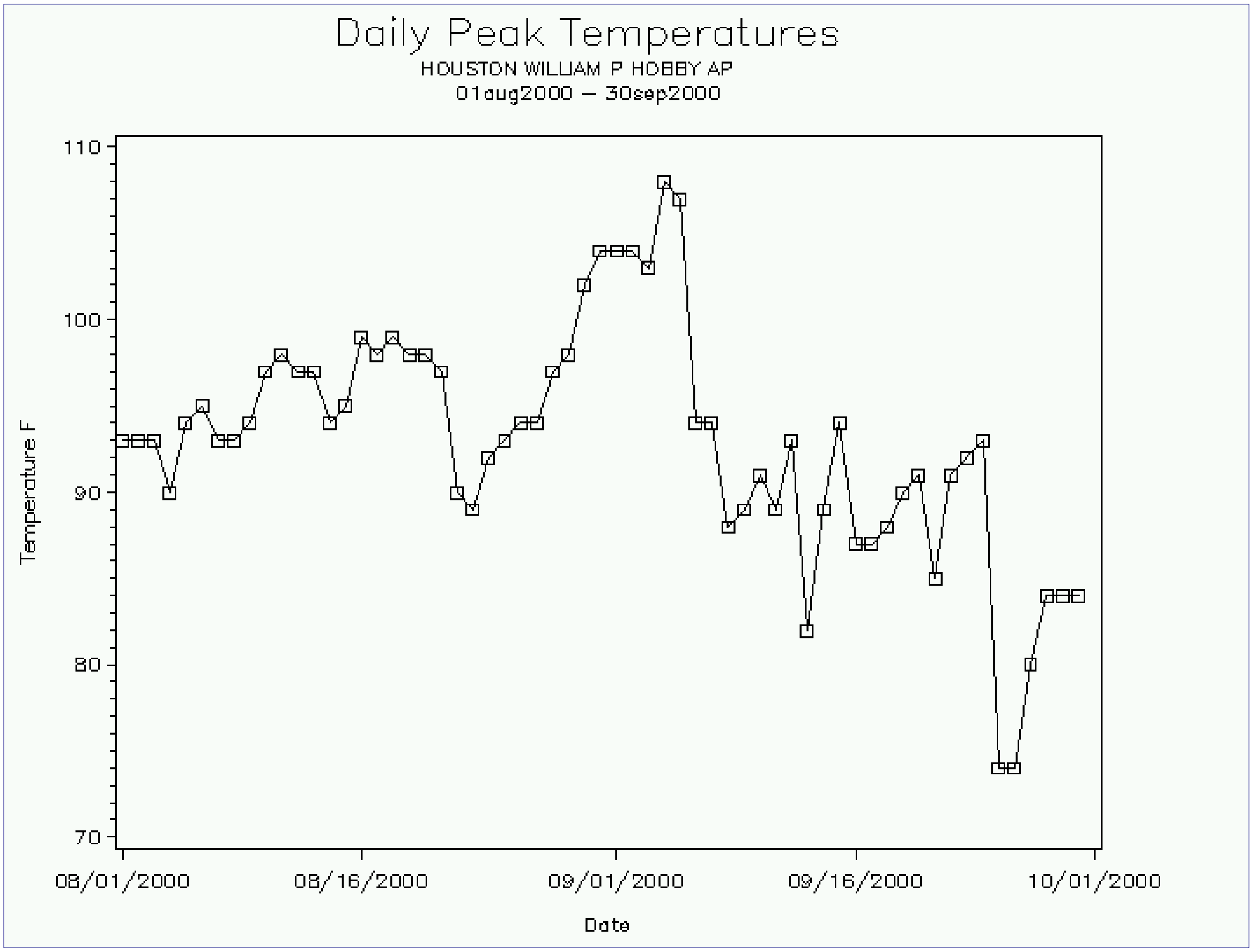


Figure 3.9-3, *Maximum Observed Temperatures at Houston Hobby, January 1, 1942 - December 31, 2003*, shows the frequency of maximum daily temperatures observed at Houston Hobby airport from January 1, 1942 to December 31, 2003. Temperature data were collected only in the winter months until 1947; thereafter, data was collected all year long, yielding a temperature record of 57 years. This figure shows how many days each maximum temperature occurred over the 57-year period. Note that peak temperatures of 104°F or higher were exceedingly rare during the period. Figure 3.9-4, *Days greater than 100F, January 1, 1942 - December 31, 2003*, focuses upon the right side of the frequency distribution, showing the number of days with the highest temperatures. Peak temperatures of 104°F or greater were observed a total of 9 days in 57 years of records. Five of these days occurred in a 7-day period in 2000; 3 occurred during a 5-day period in 1962 (August 9-13, 1962). Figure 3.9-5, *Daily Peak Temperatures at Houston Hobby, August - September 1962*, shows the peak temperatures at Houston Hobby during August-September of 1962. Figures 3.9-2 through 3.9-5 indicate that 8 of the 9 days with maximum temperatures greater than or equal to 104°F are accounted for by the two described episodes. Therefore, one could expect a multi-day episode of temperatures greater than or equal to 104°F, such as August 30 - September 5, 2000, to occur no more frequently than twice in a 57-year period.

Figure 3.9-3: Maximum Observed Temperatures at Houston Hobby, January 1, 1942 - December 31, 2003

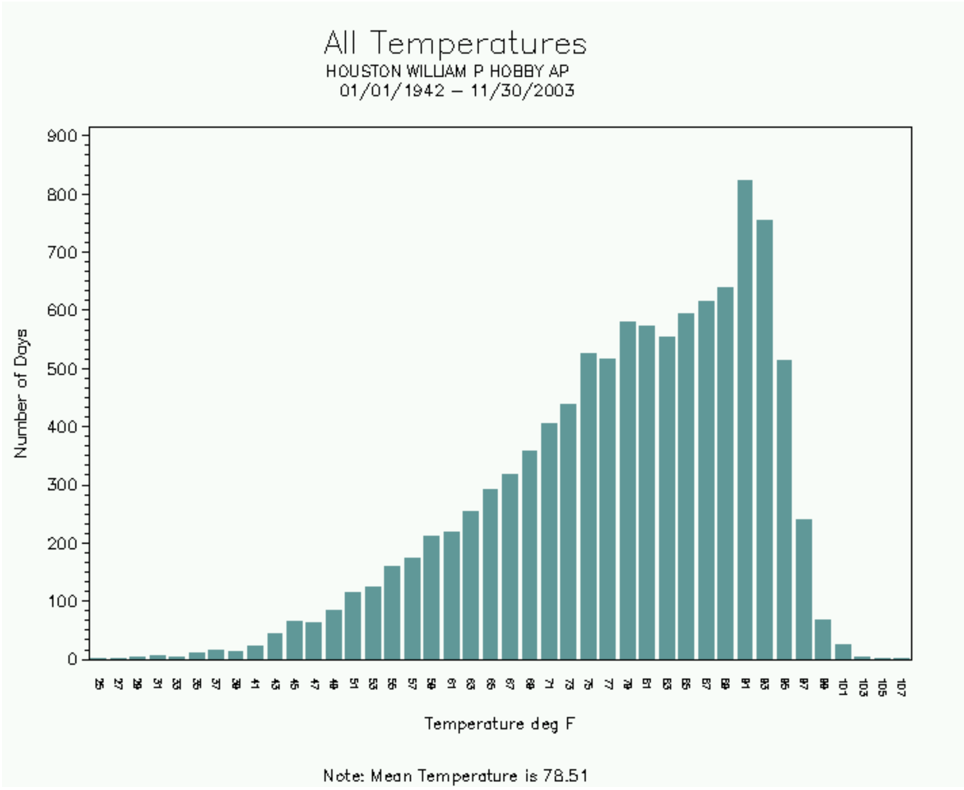


Figure 3.9-4: Days greater than 100 F, January 1, 1942 - December 31, 2003

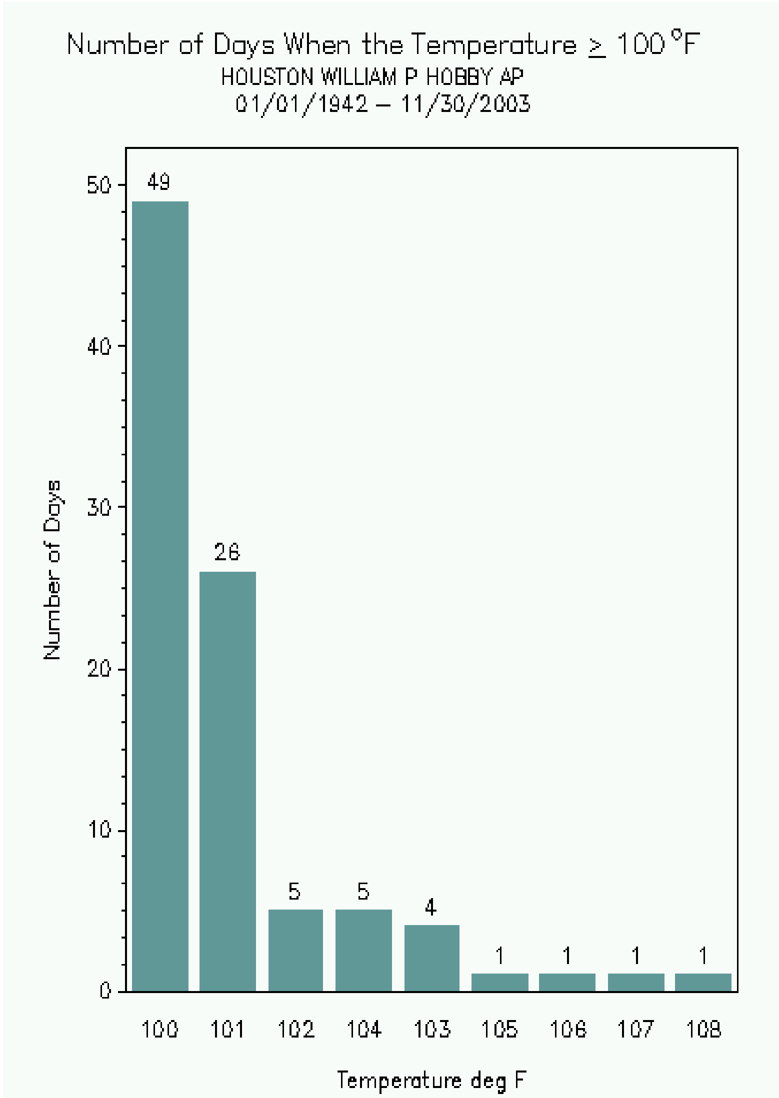
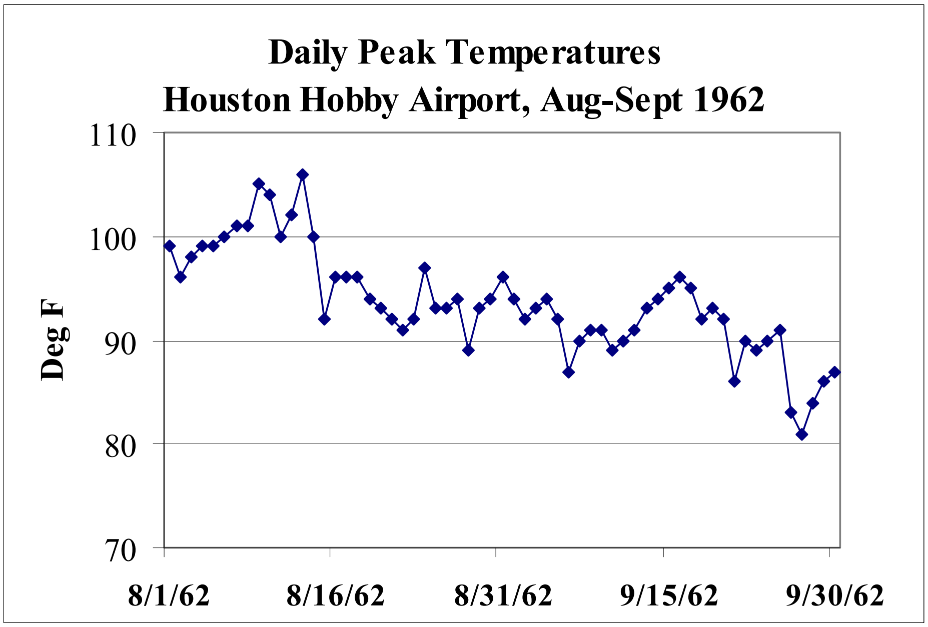
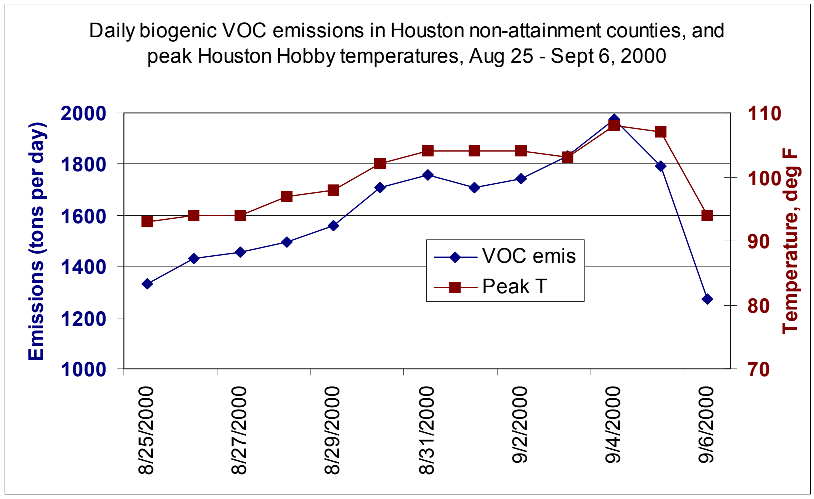


Figure 3.9-5: Daily Peak Temperatures at Houston Hobby, August – September 1962



<u>3.9.1.2 Effects of Record Heat on Biogenic Emissions</u>
The biogenic emissions are directly dependent upon temperature (Guenther et al., 1993; Geron et al., 1994). Figure 3.9-6, *Daily Biogenic Emissions and Peak Temperatures in HGB, August 25 - September 6, 2000*, shows the total daily biogenic VOC emissions in the HGB counties for each day from August 25 - September 6, 2000, along with peak temperatures at Houston Hobby. Much of the day-to-day variation seems to be explained by temperature differences. The high temperatures on these days increased the modeled biogenic VOC emissions by 30 to 45 percent relative to an average day such as August 25. Biogenic VOC emissions increase steadily as the peak temperatures increase, adding 426 tons in HGB from the August 25 total (which had a peak temperature of 93°F, the climatological average peak temperature) to the August 31 total (which topped out at 104°F). Thus, biogenic emissions were much larger on August 31 than on an typical day.

Figure 3.9-6: Daily Biogenic Emissions and Peak Temperatures in HGB, August 25 - September 6, 2000



3.9.1.3 Ozone Source Apportionment of the CAMx Modeling

The Ozone Source Apportionment Technology (OSAT) tool in CAMx was used to study the VOC-NO_x sensitivity of the environment in which the ozone was forming. The OSAT approach is described in detail in the CAMx User's Guide (ENVIRON, 2003). The User's Guide describes OSAT as follows:

> OSAT uses multiple tracer species to track the fate of ozone precursor emissions (VOC and NO_x) and the ozone formation caused by these emissions within a simulation. The tracers operate as spectators to the normal CAMx calculations so that the underlying CAMx predicted relationships between emission groups (sources) and ozone concentrations at specific locations (receptors) are not perturbed.

OSAT determines whether ozone is forming in a VOC- or NO_x -limited environment, and then keeps track of the origin of the precursors that are creating the ozone. OSAT keeps track of the limiting precursor; for example, if the ozone in a grid cell is forming in a VOC-limited environment, then OSAT assigns the formed ozone to the VOCs present in that cell. OSAT analyses were performed on base5b_psito2n2_4km files.

OSAT analyses were performed for each episode day, but only the three figures supporting the following example comparisons are included in this section. All OSAT analysis figures are available in Appendix J, "OSAT Analysis Figures for August 25-September 6." In the first example, August 25 and August 31 are compared; August 25 is representative of the meteorological conditions prevalent from August 22-August 29. In the second example, August 30 and 31 are compared; August 30 is representative of the conditions during the second half of the episode (August 30-September 5).

Figures 3.9-7, *Bayland Park: Ozone Source Apportionment, August 25 Base Case*, and 3.9-8, *LaPorte: Ozone Source Apportionment, August 25 Base Case*, show the OSAT analyses for August 25 and August 31. The August 25 OSAT was performed for the Bayland Park receptor on the west side of Houston; the August 31 OSAT was performed for the La Porte receptor on the east side of Houston. In both cases, the receptor is located relatively close to the HGB peak ozone modeled for that day. August 25 shows only a moderate contribution from HGB biogenic emissions (24 ppb) at the hour of peak ozone, and almost no contribution from biogenic emissions from outside the HGB area. However, on August 31, 78 ppb of ozone is contributed by biogenic emissions at the peak ozone hour, with 40 ppb from HGB biogenics and 38 ppb from non-HGB biogenics. The ozone contributed from biogenics is primarily formed in VOC-limited conditions, with the VOCs being supplied by biogenic VOC emissions. Figure 3.9-9, *Modeled Peak: Ozone Source Apportionment, August 31 Base Case*, shows another OSAT analysis for a different receptor, i.e., the peak modeled ozone grid cell (located over Galveston Bay) on August 31. Combined contribution from biogenics and boundary conditions yields 118 ppb, only 7 ppb below the 1-hour ozone standard. Therefore, a large portion of the ozone on August 31 at the peak grid cell and the La Porte site is difficult to control, since most of the ozone is contributed by biogenic emissions. While the model indicates that the ozone is most sensitive to VOC reductions, the VOCs that are culpable for the ozone are biogenic in origin, and therefore are not affected by any point source control strategy.

Figure 3.9-7: Bayland Park: Ozone Source Apportionment, August 25 Base Case

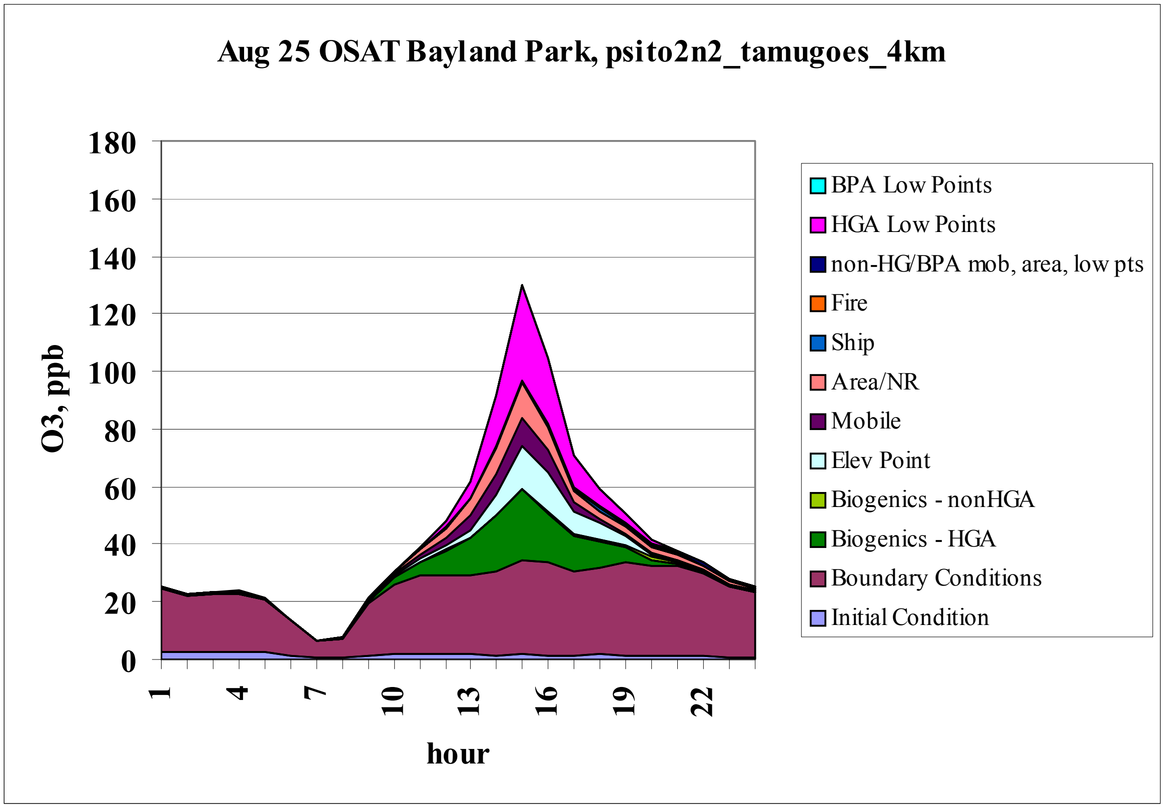


Figure 3.9-8: LaPorte: Ozone Source Apportionment, August 31 Base Case

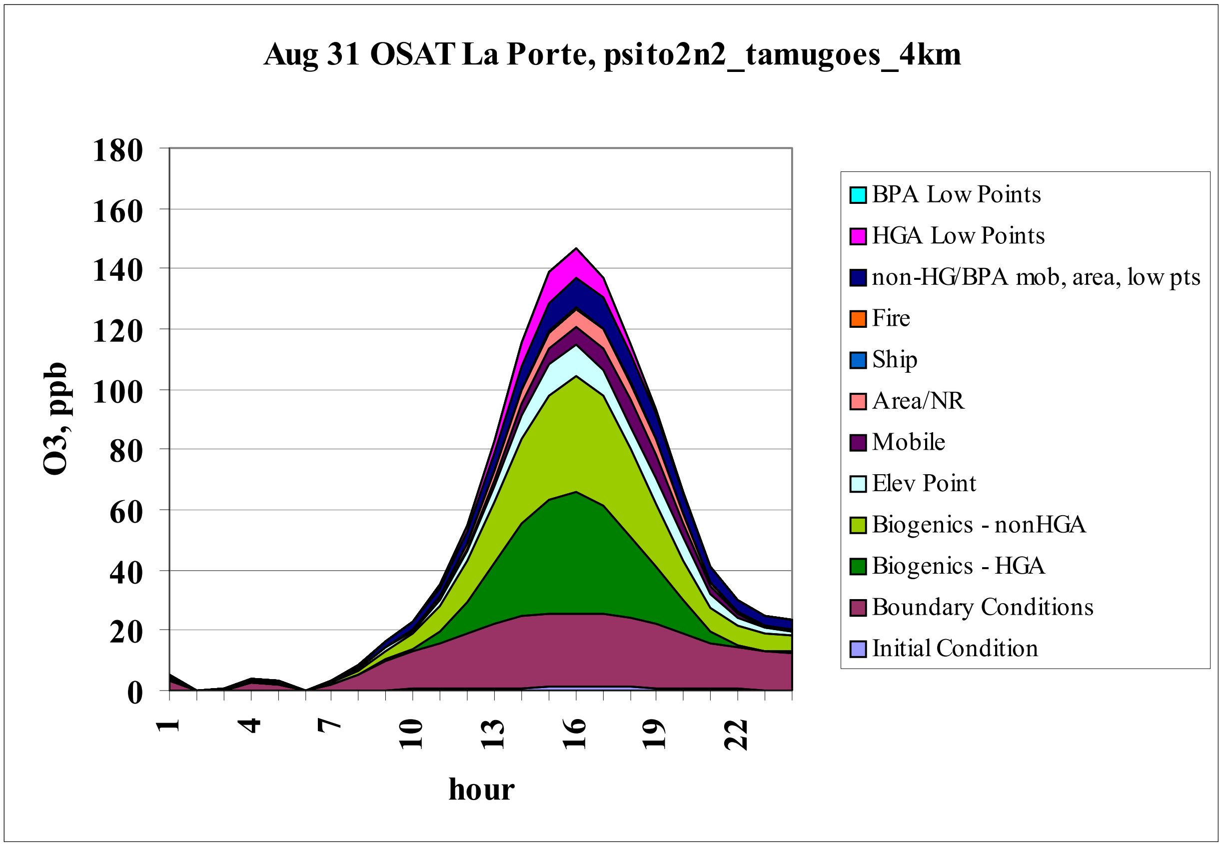
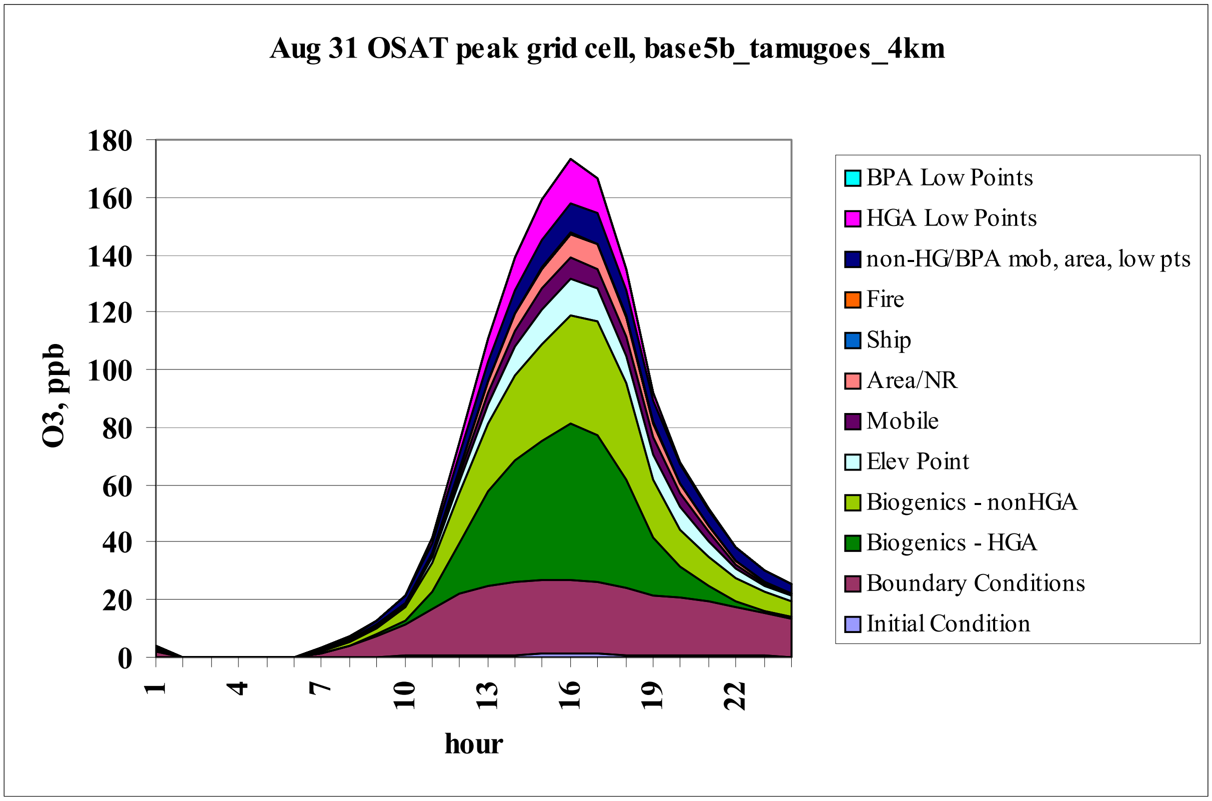
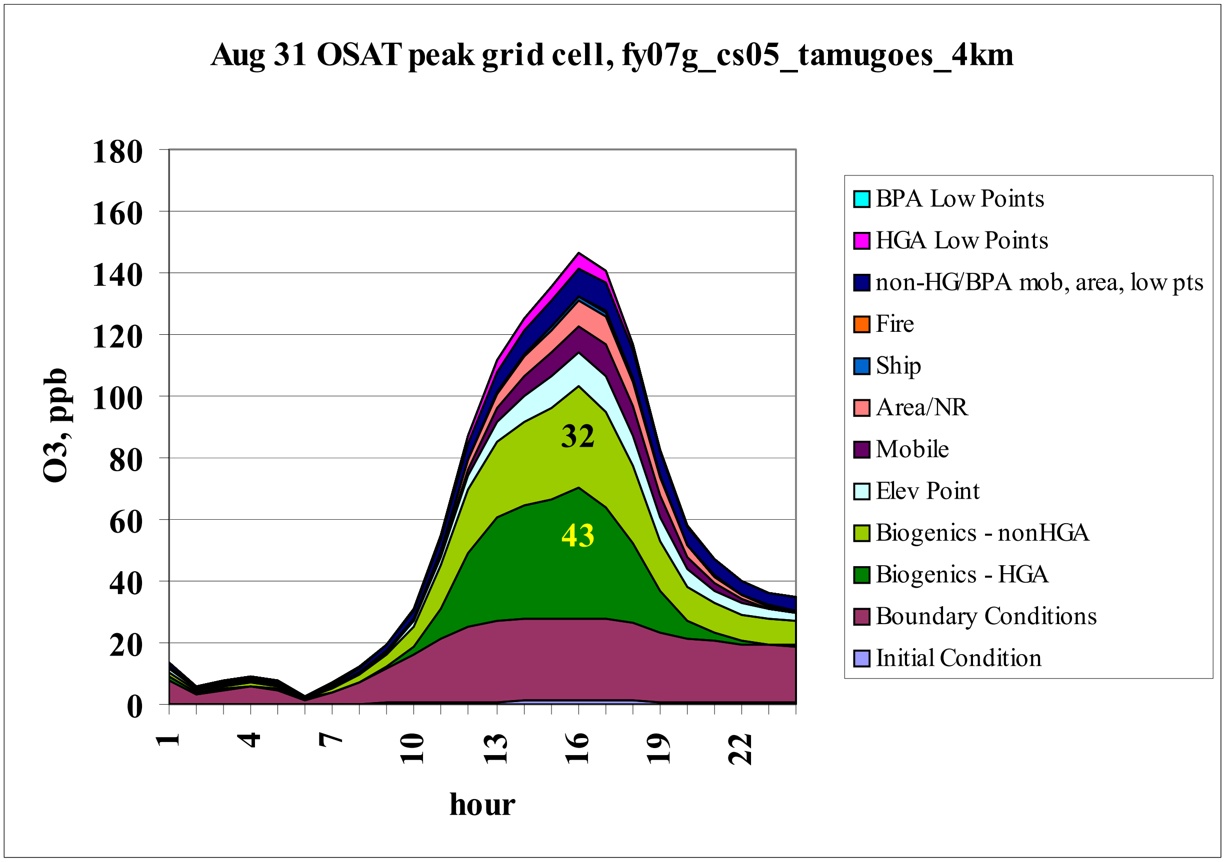


Figure 3.9-9: Modeled Peak: Ozone Source Apportionment, August 31 Base Case



OSAT was also run for August 31 after control strategies had been applied. Figure 3.9-10, *Modeled Peak: Ozone Source Apportionment, August 31 Future Case*, shows the OSAT results for the fy07f_cs05_tamugoes_4km run. Although this future case was not the final control strategy, it is fairly similar. The results show that the peak ozone at the peak grid cell within the domain is 148 ppb, 23 ppb above the 1-hour ozone standard. The non-HGB biogenics account for 32 ppb of the total peak ozone, suggesting that the control strategy falls short largely due to the biogenics contribution.

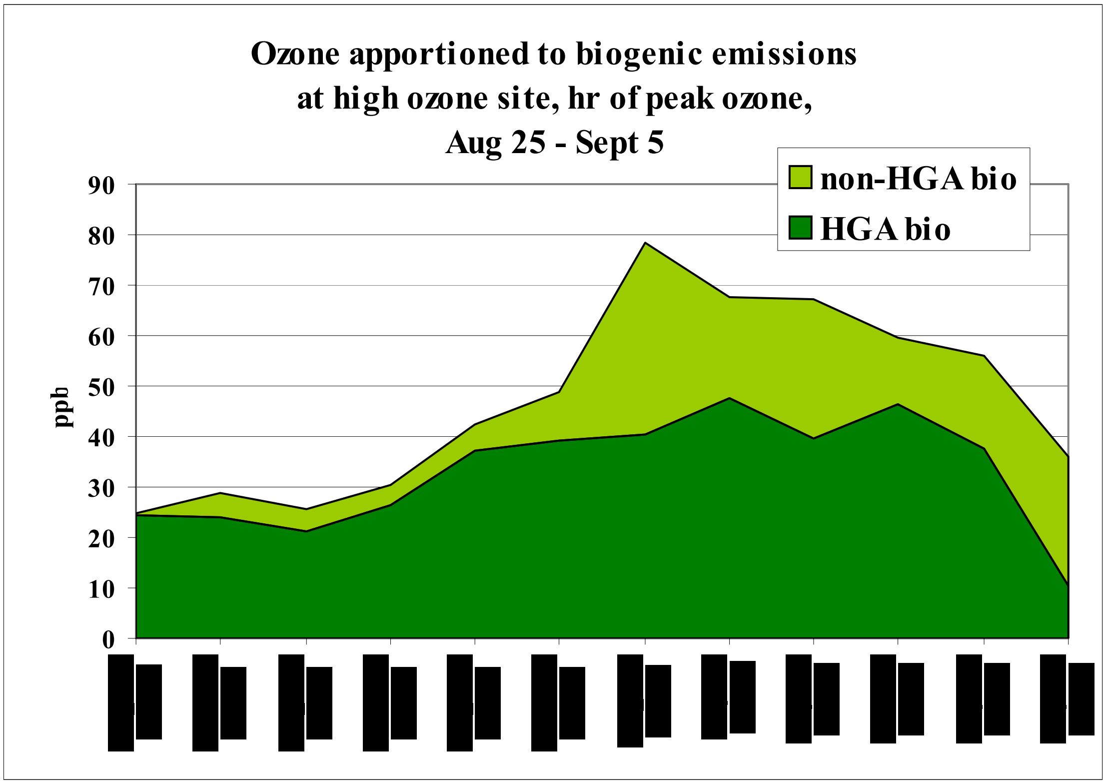
Figure 3.9-10: Modeled Peak: Ozone Source Apportionment, August 31 Future Case



Role of Non-HGB Biogenics is Greatest on August 31

Figure 3.9-11, *Biogenic VOCs from Inside and Outside HGB*, shows how much ozone is contributed by biogenic VOCs inside and outside of the HGB area for each episode day. The OSAT contributions were calculated at monitoring sites located in the vicinity of the peak modeled ozone, except for September 4-6, for which peak modeled ozone did not occur near any OSAT receptor.

Figure 3.9-11: Biogenic VOCs from Inside and Outside HGB



Modeled ozone on August 31 is more strongly affected by non-Houston biogenic emissions than any other episode day. Since several other days within the episode had conditions similar to August 31, the TCEQ sought to determine why August 31 was the only day that showed such a large contribution from non-HGB biogenics. Figures 3.9-12, *Average Morning and Afternoon Wind Direction, August 30 - September 1, 2000*, and 3.9-13, *Average Morning and Afternoon Wind Direction, September 2 - September 4, 2000,* show the average morning and afternoon wind direction on each day from August 30 - September 4. August 30 and September 4 had similar average morning wind direction, but September 4 had very different afternoon winds, because the peak observed ozone occurred in Galveston, whereas on August 30 and 31, the peak occurred at La Porte. August 30 is the day most similar to August 31, yet it showed much less contribution from non-HGB biogenics than August 31. Figure 3.9-14, *La Porte: Ozone Source Apportionment, August 30 Base Case*, shows the OSAT analyses at the La Porte site for August 30. For the peak hour at La Porte on August 30, about 40 ppb of ozone is formed from HGB biogenic emissions, but only 9 ppb is formed from biogenic emissions outside the 8-county HGB nonattainment area. On August 31, however, about the same amount of ozone is formed from HGB biogenics, but over 38 ppb ozone is formed from biogenic emissions outside HGB–a fourfold increase in the amount of ozone contributed by non-HGB biogenics.

Figure 3.9-12: Average Morning and Afternoon Wind Direction, August 30 - September 1, 2000

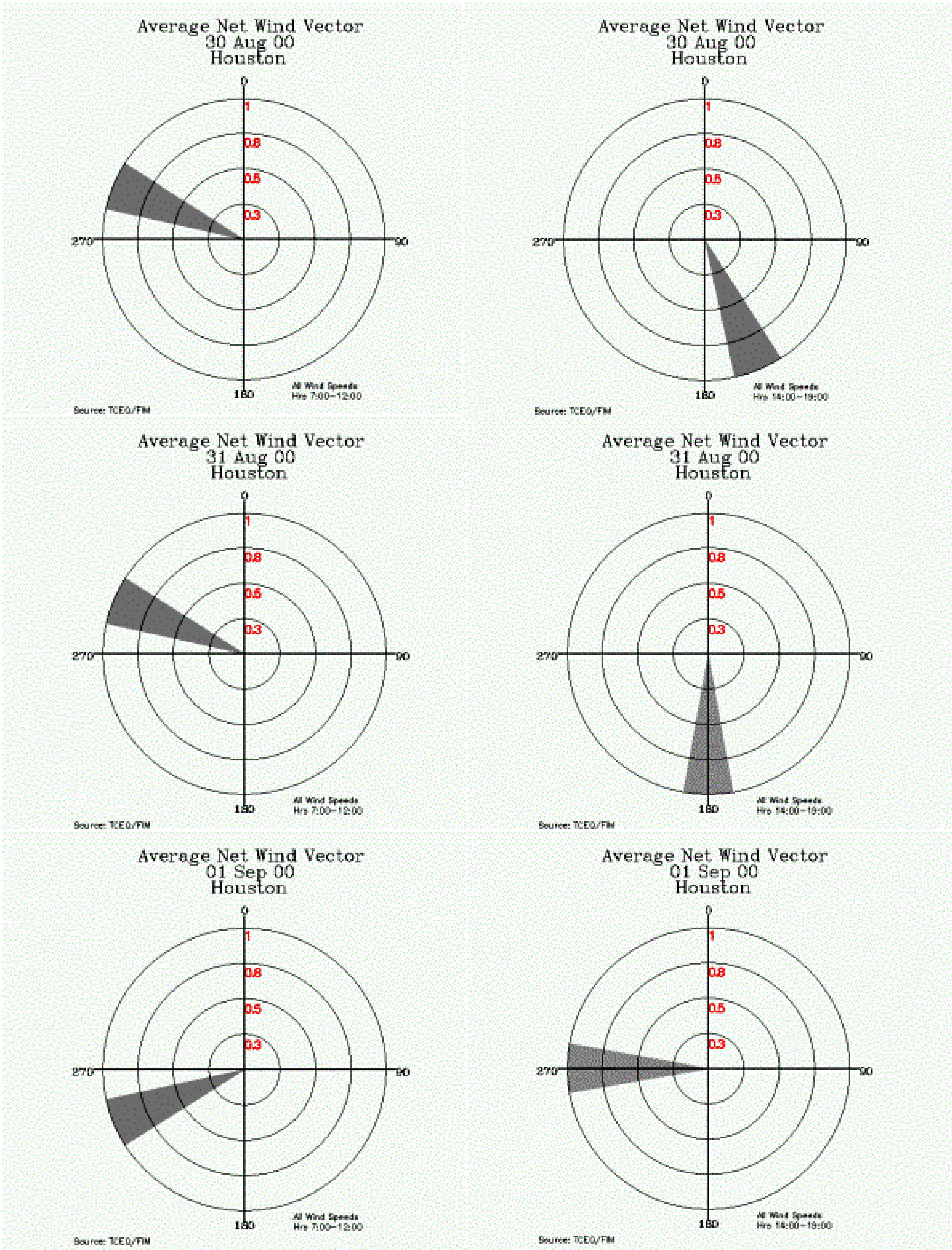


Figure 3.9-13: Average Morning and Afternoon Wind Direction, September 2 - September 4, 2000

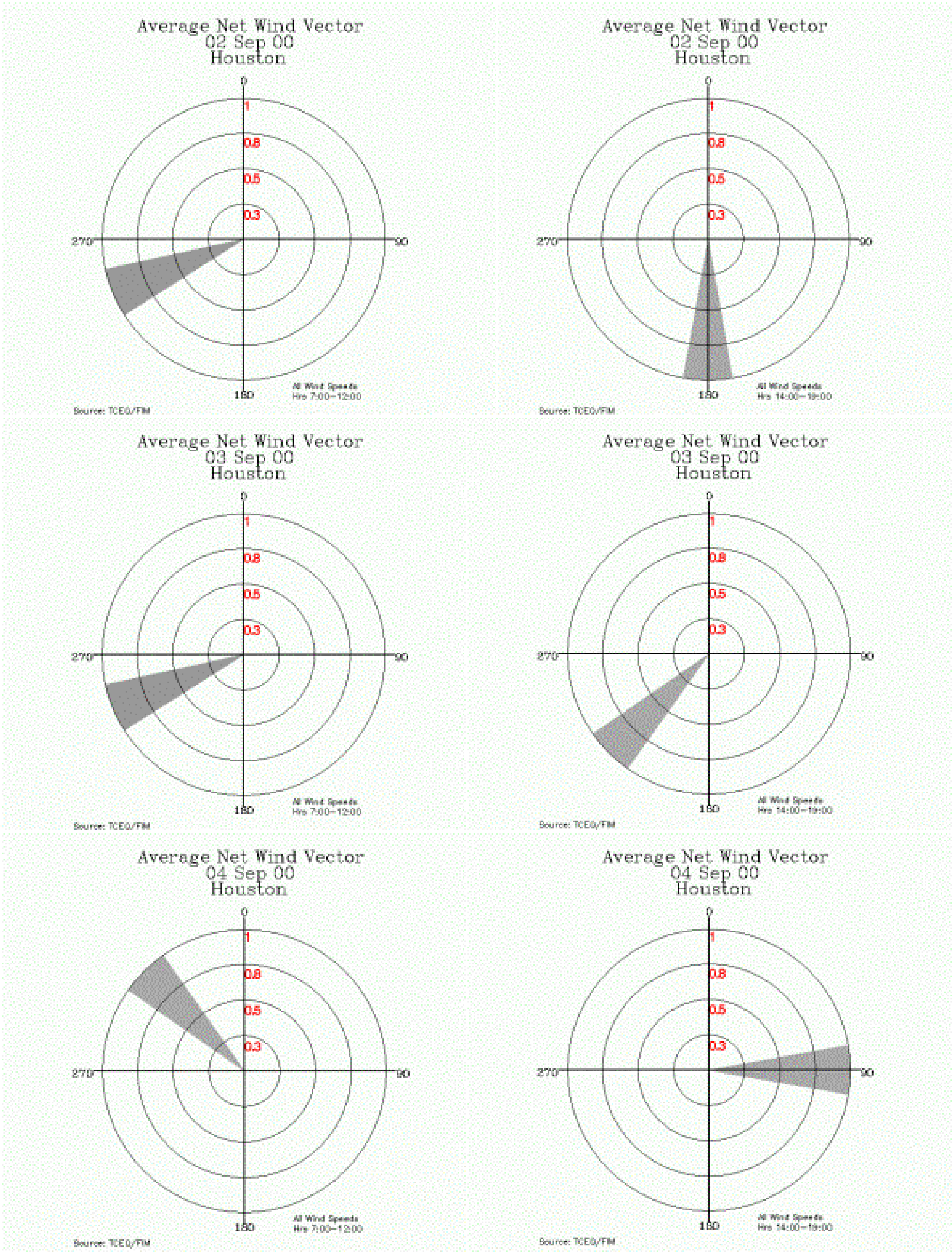
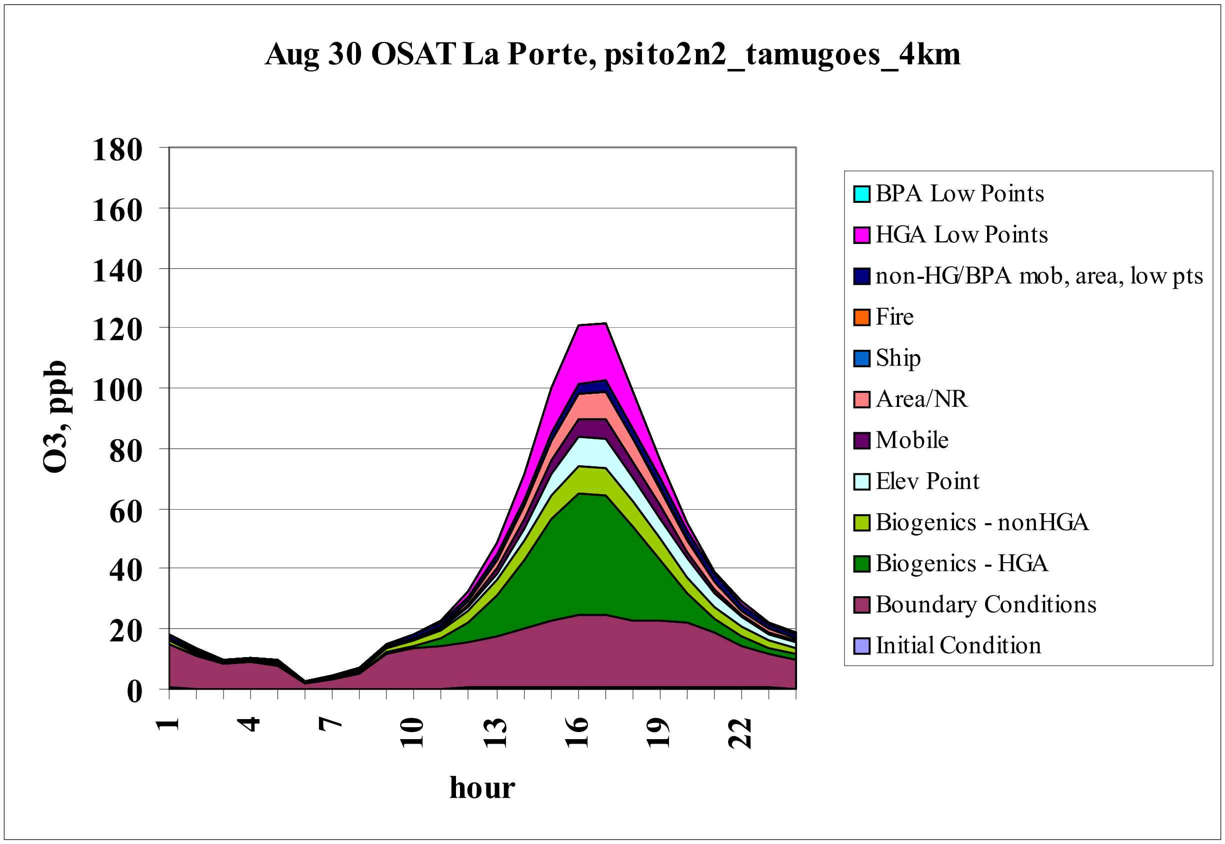


Figure 3.9-14: LaPorte: Ozone Source Apportionment, August 30 Base Case



While the morning wind directions were similar for August 30 and 31, the morning wind speeds were different. Figures 3.9-15, *10:00 a.m. CAMX Winds, August 30*, and 3.9-16, *10:00 a.m. CAMX Winds, August 31*, show 10:00 a.mm CAMx winds on August 30 and 31, respectively. Winds on both days are from approximately the same direction, but on August 31 morning winds are stronger. The stronger winds would allow greater transport of ozone and ozone precursors from central Texas biogenic emissions into the HGB area. To verify the transport of ozone and ozone precursors into the HGB area, ozone at sites within the HGB area that are primarily influenced by background ozone were examined, as opposed to those not influenced by the urban and industrial areas of Houston.

Figure 3.9-15: 10:00 a.m. CAMX Winds, August 30

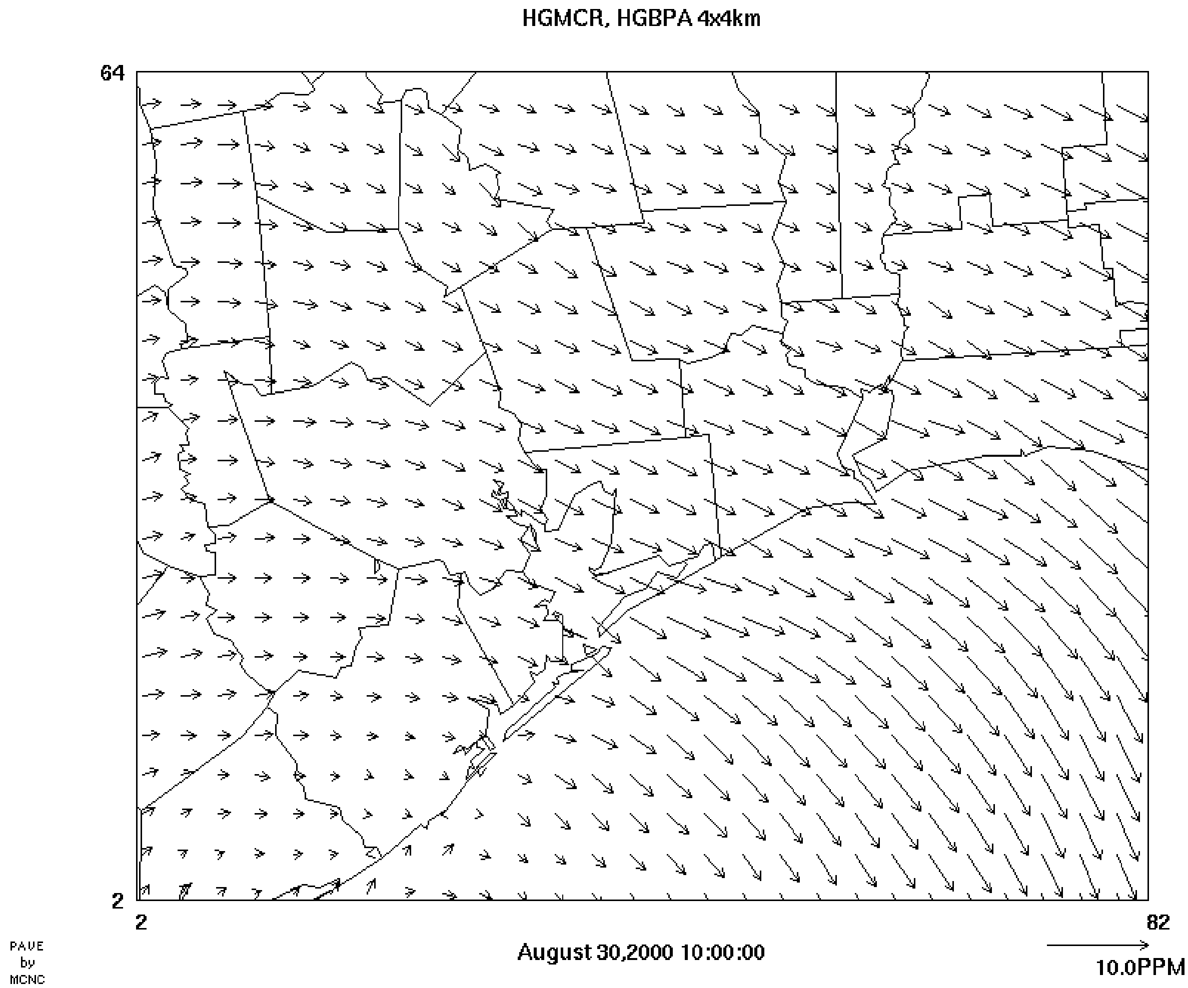
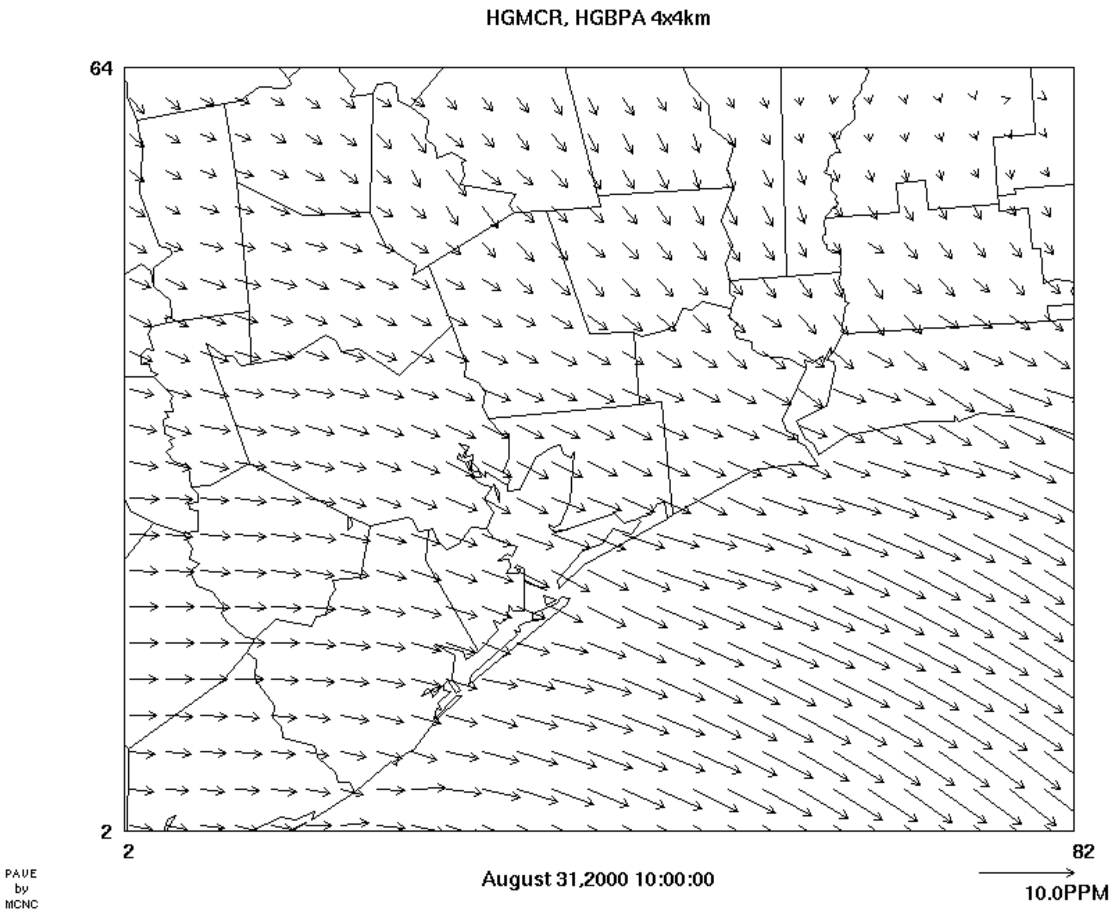


Figure 3.9-16. : 10:00 a.m. CAMX Winds, August 31



The contribution of non-HGB biogenic emissions to peak ozone is larger on August 31 than on any other day during the episode. The enhanced non-HGB biogenic contribution to peak ozone on August 31 seems to be due to transport from areas northwest of Houston, combined with the record high temperatures, which increased biogenic emissions.

The Role of Background Ozone on August 31

Several sites were identified as background sites for August 30 and 31. Figure 3.9-17, *Background Ozone Sites for August 30 and 31*, shows the locations of these five sites. Table 3.9-2, *Background Ozone Concentrations on August 30-31, 2000 in ppb*, shows the maximum ozone concentrations that occurred at five different background sites before the afternoon wind shift occurred. After the wind shift occurs, the sites are no longer representative of background conditions.

Figure 3.9-17: Background Ozone Sites for August 30 and 31

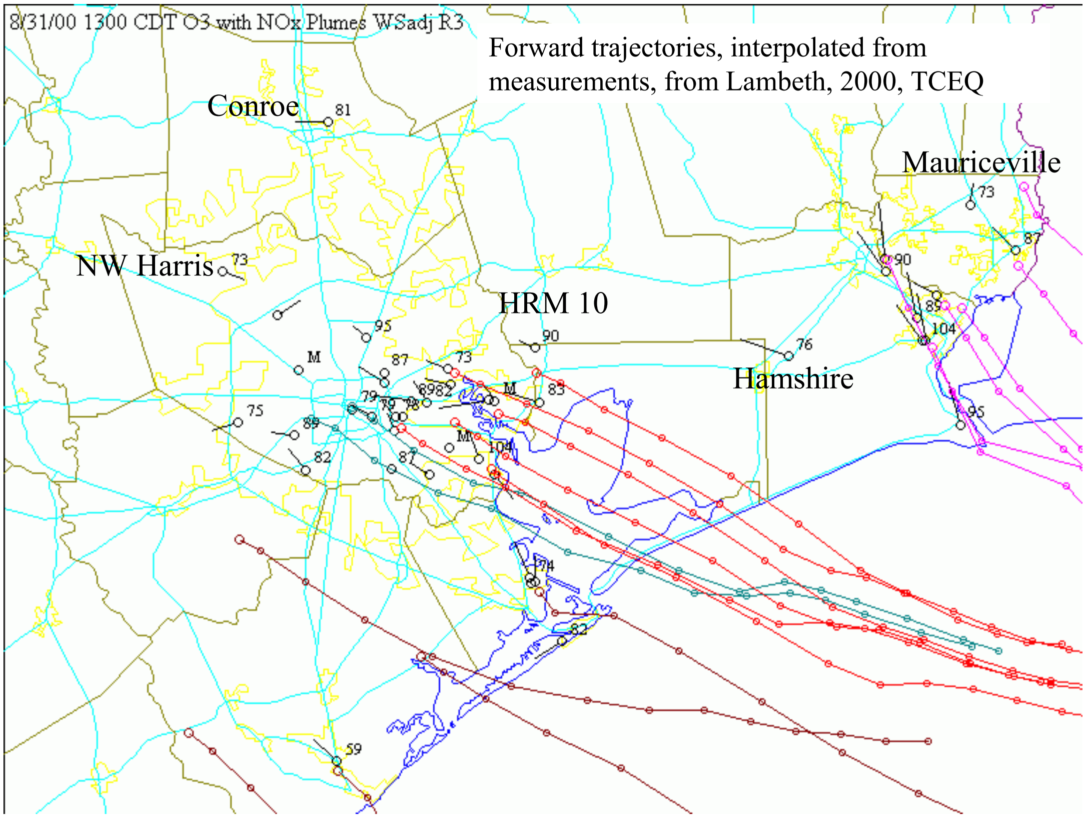


Table 3.9-2: Background Ozone Concentrations on August 30-31, 2000 in ppb. Values represent the maximum ozone concentration observed at the background site before afternoon wind shift.		
Site	August 30 ozone (ppb) and time CST	August 31 ozone (ppb) and time CST
Conroe	59 ppb, 1400	81 ppb, 1300
Northwest Harris	53 ppb, 1300	68 ppb, 1200
HRM 10	70 ppb, 1500	90 ppb, 1300
Hamshire	63 ppb, 1500	84 ppb, 1500
Mauriceville	57 ppb, 1600	75 ppb, 1400

Background concentrations of ozone are approximately 20 ppb higher on August 31 than on August 30. The increased background ozone is consistent with the OSAT results that show a large contribution of ozone associated with non-HGB biogenic emissions.

High temperatures throughout eastern Texas and western Louisiana

Data were presented earlier in this section documenting the occurrence of all-time record high temperatures in Houston from August 30 - September 5, 2000. Other data are introduced in this paragraph which indicate that temperatures during the same time period were unusually high for all of southeast and eastern Texas, as well as western Louisiana. Graphs of data were obtained from the Southern Regional Climate Center at http://maestro.srcc.lsu.edu/temp_precip_2000.html for nine weather stations in east Texas and west Louisiana (Dallas, Waco, Austin, San Antonio, Corpus Christi, Victoria, Houston, Port Arthur, and Lake Charles, Louisiana). These graphs, available in Appendix K, show average minimum and maximum temperatures from 1961-1990 vs. the actual minimum and maximum temperatures for each day of 2000. Figure 3.9-18, *High Temperatures in 2000 in Austin*, an example figure, presents historical temperature data for Austin for 1961-1990, and for 2000. The unusually high temperatures recorded at all of these stations are likely to cause higher than normal biogenic emissions. Hence, the data are consistent with the OSAT analysis that shows high contribution of biogenic VOC emissions to ozone formation on those days. They are also consistent with the high background ozone concentrations that entered the HGB area from the west on August 31. The models show that high temperatures led to high biogenic emissions, and then the combination of biogenic VOC with NO_x plumes from anthropogenic sources in central and east Texas resulted in relatively high ozone concentrations (70 to 90 ppb). The westerly winds on August 31 carried the ozone into Houston, as seen by the elevated concentrations at ground monitors on that day on the west side of Houston, and by the DOE aircraft measurements, which show background ozone concentrations outside of the industrial plumes of 80 to 100 ppb (Daum et al., 2004).

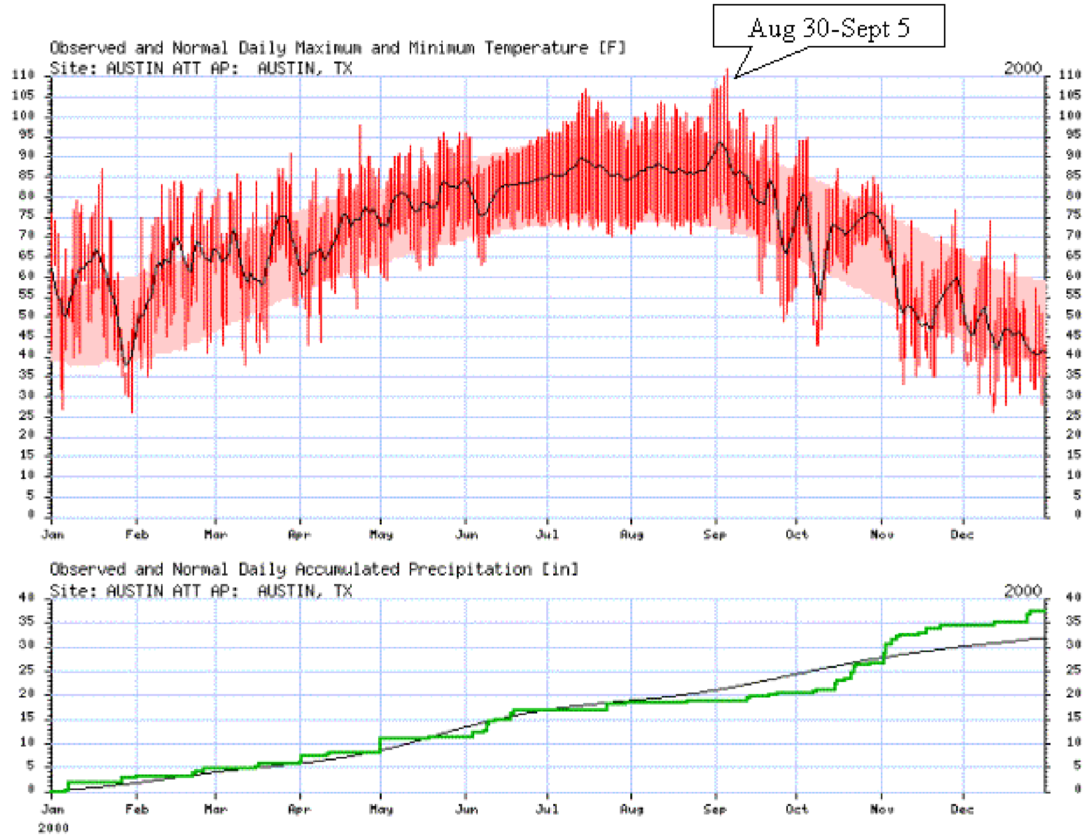


Figure 3.9-18: High Temperatures in 2000 in Austin

Testing the Effects of Record Temperatures on Photochemical Modeling Results

A recent study examined the relationship between ozone and temperature, using photochemical modeling. Aw and Kleeman (2003), used the CIT/UCD 3-D Eulerian source-oriented external mixture air quality model. Uniform increases of temperature by +2 K (+3.6°F) and +5 K (+9.0°F) were investigated, while holding absolute humidity steady. Most emissions were held steady for the different temperature scenarios, except for the evaporative emissions from mobile sources, which were varied with temperature according to the EMFAC-7G emissions model. The maximum ozone perturbation for each scenario was +7 ppb and +16 ppb, respectively, with the maximum perturbation located in the vicinity of the peak ozone value. When the sensitivity analyses were repeated with constant relative humidity, the maximum perturbations decreased slightly, e.g., for +5 K scenario, maximum increase was +14 ppb.

A temperature sensitivity on ozone was run for August 31 to verify the effect of the record temperatures on ozone for this day. Two different test scenarios were run for both the base case and future case (2007). First, the temperature and absolute humidity input for a more typical hot summer day (August 25) were run in the model with emissions, winds and other meteorological parameters from August 31 to determine the effects of temperature and humidity alone. August 25 was chosen because 194 ppb of ozone was observed on that day, so it is clear that conditions were suitable for high ozone formation. In addition, the maximum temperature was 96°F, which is closer to the climatic norm.

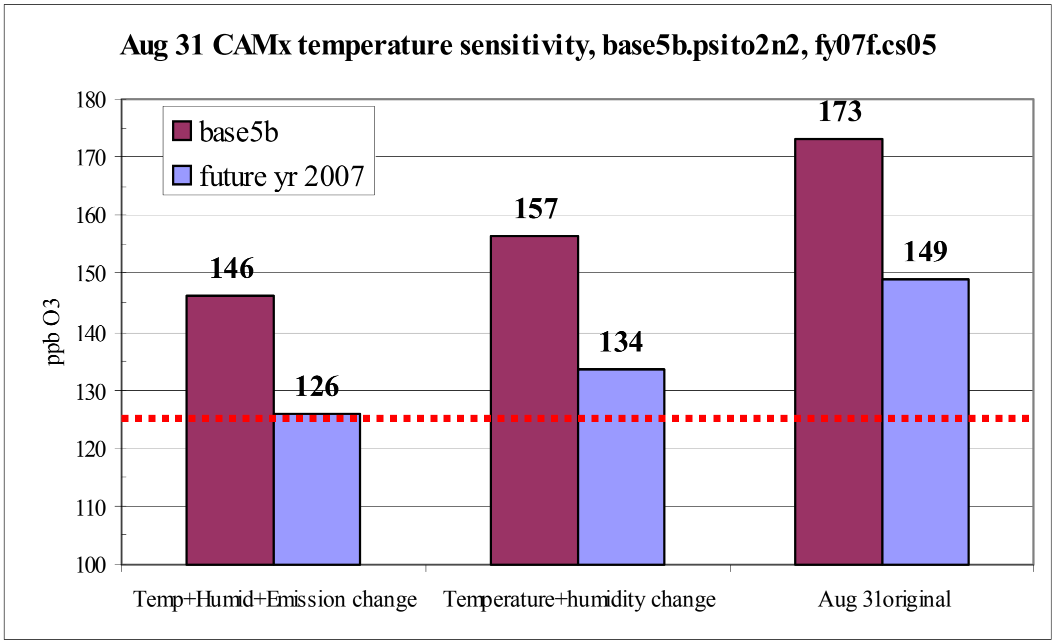
In the second test scenario, emissions files from August 31 were replaced with files from a cooler day, as well as replacing the August 31 data with cooler temperatures from August 25. The second scenario therefore accounts for both the direct temperature effects on ozone chemistry, and the indirect temperature effects on certain emission types. Winds and other meteorological parameters for August 31 were still included. For area and biogenic emissions, August 25 emissions were chosen. The electrical generating unit point source emissions were also changed to August 25 emissions, and the non-electrical generating unit point sources were not changed, i.e., the special inventory emissions for August 31 for those sources was retained. However, mobile source emissions calculated for August 21 were substituted in this scenario, in order to match the VMT characteristics between the cooler scenario and August 31. August 25 mobile source emissions could not be directly substituted, because it is a Friday, and therefore it has different VMT characteristics than August 31, which was a Thursday. August 21 was a Monday, and August 31 was a Thursday, hence, they both have the same VMT characteristics.

Effective mixing heights for August 31 were used in all scenarios. Comparisons of mixing heights from the MM5 output used for August 25 and August 31 showed that the August 25 simulated mixing heights were very similar to those simulated for August 31. Therefore, the modeled August 31 effective mixing height information was used in all of the scenarios.

A total of three scenarios is presented: (1) a standard run using August 31 meteorology and emissions ("Standard"), (2) a run for which August 25 temperature and absolute humidity files were substituted, but August 31 emissions, winds and other met parameters were still used ("TH"-Temperature/Humidity) and (3) a run that used August 25 temperature and absolute humidity files, August 25 area, point and biogenic source emissions files, August 21 mobile source emission files, and August 31 winds and other met parameters ("THE"-Temperature/Humidity/Emissions). Each scenario was run for the base case and future case. The tests show how the model responds to changes in temperature and temperature-dependent emissions, but probably should not be used to show attainment, due to potential physical differences that may result from pairing temperatures from one day with winds from another day.

Figure 3.9-19, *Temperature Sensitivity: Base Case and Future Case Peak Ozone, August 31*, shows the peak ozone results for the three scenarios, for both the 2000 base case modeling (base5b_psito2n2), and for the 2007 future case (fy07f, cs05) modeling, which includes an ozone control strategy package. Although CS-05 is not the final control package, it is similar to CS-08, and conclusions from this analysis should be equally valid for the newer future control case.

Figure 3.9-19: Temperature Sensitivity: Base Case and Future Case Peak Ozone, August 31



Decreasing only the temperature and humidity caused peak ozone to drop by 16 ppb. When the emissions are decreased as well, peak ozone drops by another 11 ppb, for a total drop of 27 ppb for all temperature effects. These decreases occurred in both the base case and future case. These results suggest that the model is very sensitive to a 9°F drop in average midday temperatures. In this case, 9°F represents the difference between a typical hot summer day and record-breaking heat.

The response of the model to controls is nearly identical in all three temperature scenarios, with a reduction of peak ozone by about 24 ppb when the control strategies are in place. Before any temperature adjustments are made, the peak control strategy CS-05 ozone is 149 ppb, 24 ppb above the 1-hour ozone standard.

One of the scenarios ("TH") is comparable to the Aw and Kleeman (2003) study. The "TH" scenario yielded a 16 ppb decrease in peak ozone for a 6°C decrease in temperature--fairly consistent with the results from Aw and Kleeman--which also showed a 16 ppb decrease for a 5°C temperature drop. The two cases are not identical, in that Aw and Kleeman also varied the mobile source emissions, whereas the "TH" scenario did not. Also, the current study varied absolute humidity as well as temperature, but Aw and Kleeman held absolute humidity steady. But the similarities in the method and the results between the two studies supports the findings of this study.

The temperature sensitivity results indicate the model is fairly sensitive to a 9°F change in temperature and concomitant changes in temperature-dependent emissions, perhaps more sensitive than previously expected. The results suggest that if the temperatures had been closer to normal on August 31, the peak ozone would have responded more fully to the control strategies, and would have been considerably closer to the 1-hour ozone standard.

3.9.1.4 Findings and Conclusions

August 31 is the only day during the August 25 - September 6 episode that is not reasonably responsive to the control strategies for the following reasons.

- Temperature effects on biogenic emission inside the HGB area: Additional biogenic emissions in the HGB area resulted from high temperatures during the August 30 - September 5, 2000 time period. The record high temperatures allowed modeled biogenic emissions to increase 30 to 45 percent above average levels.
- Temperature effects on biogenic emissions outside of the HGB area: High temperatures through the region led to higher than normal biogenic emissions that were available for transport into the HGB area. The OSAT tool in the CAMx model estimates that over 38 ppb of the August 31 ozone was formed from biogenic emissions outside of the HGB area, a four-fold increase over other days in the episode.
- Greater transport of biogenic emissions from outside of the HGB area: Modeled ozone on August 31 is more strongly affected by non-HGB biogenic emissions than any other episode day because of an unusual westerly wind pattern coupled with extremely high temperatures. The strong contribution from non-HGB biogenics results in background ozone on August 31 being approximately 20 ppb higher than on August 30.

In summary, the TCEQ photochemical model sensitivity analyses show that the modeled ozone is sensitive to changes in temperature and temperature-dependent emissions. Results are consistent with those found by Aw and Kleeman (2003). Modeled ozone on August 31 is not reasonably responsive to controls largely because of the high contribution of biogenic emissions to peak ozone, including biogenic emissions that originate outside of the HGB area. The large contribution from biogenics is due to the record high temperatures observed during this time, and brisk morning winds that transported ozone and precursors from outside the HGB area. The sensitivity analysis suggests that the peak ozone on August 31 would have responded more fully to the proposed controls if the temperatures had not been at record levels. Similar temperatures have occurred only twice in the past 57 years. Therefore, the conditions that led to the resistance of August 31 to the control strategies are infrequent, and are unlikely to occur once per year.

3.9.2 Additional Reductions Expected By 2007

A number of additional reductions to emissions of NO_x and VOC that are not explicitly modeled will occur in the next three years. Taken together, these reductions will provide additional air quality benefits beyond those included in CS-08.

3.9.2.1 Collateral VOC Reductions

Because reductions to emissions of HRVOCs are expected as a result of controls implemented through this SIP revision, much attention will be paid to improving operations at large facilities in the HGB area. Because of the types of sources emitting HRVOC, it is difficult to determine how each facility will choose to comply with the HRVOC requirements, however, some controls may be placed on process streams containing a mixture of VOCs.

At present, quantification of these ancillary reductions is difficult, due to the high level of uncertainty in how each facility may choose to comply with the HRVOC caps and in identifying sources subject to those caps. Assuming all VOCs sharing a common emission point with capped sources are reduced by the same amount, collateral reductions could be a significant source of reduction to atmospheric ozone production potential, i.e. reactivity, depending on the composition of the co-located VOC stream.

One example of a collateral VOC reduction could occur at cooling towers where control requirements require that the owner operator of monitor for leaks. Where an HRVOC stream is either mixed with an other VOC (OVOC), the detection of HRVOC leaks will result in a reduction of OVOCs as well. Additionally, the rule revision associated with this SIP revision contains language preventing these collateral reductions from being credited for use as offsets. In other words, these reductions will not return to the airshed as future growth.

3.9.2.2 Potential Reductions Resulting from EISM

To increase the potential for success of this SIP strategy, a program to help industry respond rapidly to increases in ambient HRVOC concentrations detected by these monitors is under development. The Environmental Monitoring Response System (EMRS) is a cooperative monitoring venture between Houston Regional Monitoring Network, HGB area Industry and the TCEQ which is designed to measure Photochemical Assessment Monitoring Sites (PAMS) VOC species close to point source clusters.

A primary goal of EMRS is to prevent HRVOC emissions from creating situations that may lead to high levels of ozone. This goal will be accomplished by the near real time monitoring and rapid response built into the program.

Other goals of EMRS include the ability to measure the effectiveness of HRVOC rules, to correlate HRVOC levels with ozone, to determine which other VOCs should also be considered HRVOCs, to provide high resolution data that will allow Emissions Inventory improvements, and to provide a reasonable alternative to costly fence line monitoring.

3.9.2.3 Emission Event Database with Lower Reportable Quantities

Another tool also expected to result in additional reductions is the web-based access to an emission event database incorporating lower reportable quantities of VOCs beyond just the HRVOCs of most concern. As public awareness of the number and amount of these releases increases, industry is expected to respond in a manner similar to their approach for the Toxics Release Inventory program. Awareness and documentation of these events should prompt industry to begin to evaluate not just the causes of these events but also the causes of near events and institute an enhanced program to ensure that even the potential of an event is significantly minimized. In fact, the East Harris County Manufactures Association has a significant initiative underway to evaluate and communicate among themselves which best management practices are most effective.

3.9.2.4 Shutdown/Mothballing of Electric Utilities

As the Texas utilities continue their transition to a fully deregulated market, there will be a continued shutdown and replacement of the existing less efficient plants as newer more cost effective plants begin production. Predicting the market forces that will drive these shutdowns, as well as the timing of retiring the older plants, would be difficult. However, it is reasonable to assume that additional reductions currently unaccounted for will result from this process. Since, at this time, the modeling only excludes units that have been cancelled (air permit withdrawn or inclusion on the Public Utility Commission of Texas Project Cancellation list) or will be retired/reduced under agreed orders, the current future case modeling inventory undoubtedly includes sources that will in fact be mothballed or retired in and/or prior to 2007. The PUC maintains a list of units are expected to be out of service in the near future (see http://www.puc.state.tx.us/electric/reports/gentable.pdf).

The TCEQ will continue investigating improved methods for predicting future emissions from electric generation units for future modeling activities.

Taken together, the above reductions will undoubtedly provide substantial additional benefits to the region's air quality beyond those already demonstrated for CS-08.

3.9.2.5 Non-EGUs from Permit Applications Prior to January 2, 2001

A correction was applied to electric generating units (EGUs) to account for the expected electricity demand in 2007. This correction assumed that only 75 percent of allowances assigned to newly permitted EGUs would be used, i.e., emissions from these units would be 75 percent of the allowances that are current available for use for these units.

No correction was made to non-EGUs (NEGUs) since a comparable relationship is not available that would provide enough confidence for direct inclusion into the model. However, an examination of years 2002 and 2003 indicate that only 33 to 39 percent of the allowable allowances for permitted facilities were used. NEGUs permitted prior to the initiation of the MECT program, but not in operation for sufficient time to establish a baseline are allowed to operate at their allowable levels until a baseline has been established. Typically these facilities are not operating at their allowable rates, but significantly below those values. As these newly permitted facilities establish baselines from which to grant "actual" allowances, the amount of cap in the HGB area will decrease overall. This decrease has not been accounted for in the modeling.

3.9.3 Comprehensive Ozone Metrics

Figures 3.9-20, *Peak Modeled 1-Hour Ozone Concentrations for Base & Future Control Cases*, through 3.9-23, *Exceedance Area-Hours-ppb for Base & Future Control Cases*, show graphically the benefits from CS-06a compared to the uncontrolled base case and to CS-03. The first figure shows the peak ozone concentrations reported above in Table 3.7-2, while the second shows the area (in Km^2) of exceedance, that is, the surface area where modeled ozone exceeds 125 ppb at any time during a day. The third figure shows area-hours of exceedance. Area-hours is similar to area of exceedance except that each grid cell is counted once for each hour that its concentration exceeds 125 ppb. This metric measures both area and temporal extent of exceedance. Finally, the last figure of this set shows area-hours-ppb, which adds the severity (i.e., the magnitude of the exceedance above the standard) to the equation. This latter metric is a comprehensive measure of ozone pollution in an area.

Following Figure 3.9-23 are four figures (Figures 3.9-24 through 3.9-27) which provide these same metrics, but this time comparing the new future control case CS-08 with its predecessor CS-06a. These figures show that the benefits with CS-08 are greater than those originally calculated for CS-06a. There are only minimal differences in the actual levels of control between CS-06a and CS-08; the main differences in ozone concentrations are due to model enhancements and corrections.

Figure 3.9-20: Peak Modeled 1-Hour Ozone Concentrations for Base & Future Control Cases

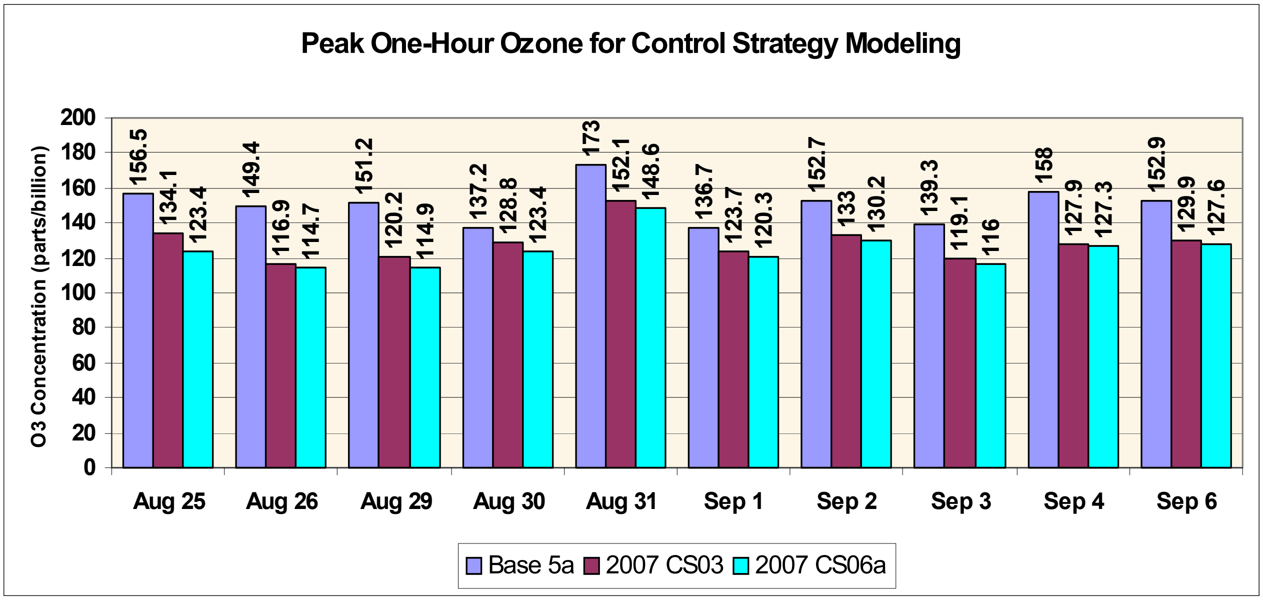


Figure 3.9-21: Exceedance Area for Base & Future Control Cases

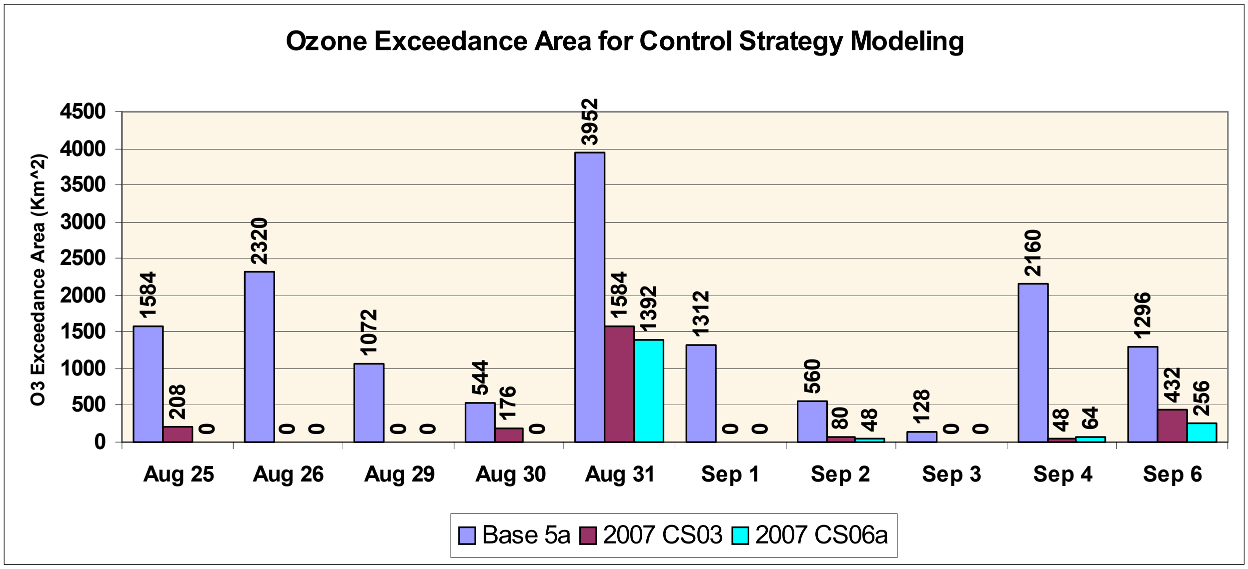


Figure 3.9-22: Exceedance Area-Hours for base and Future Control Cases

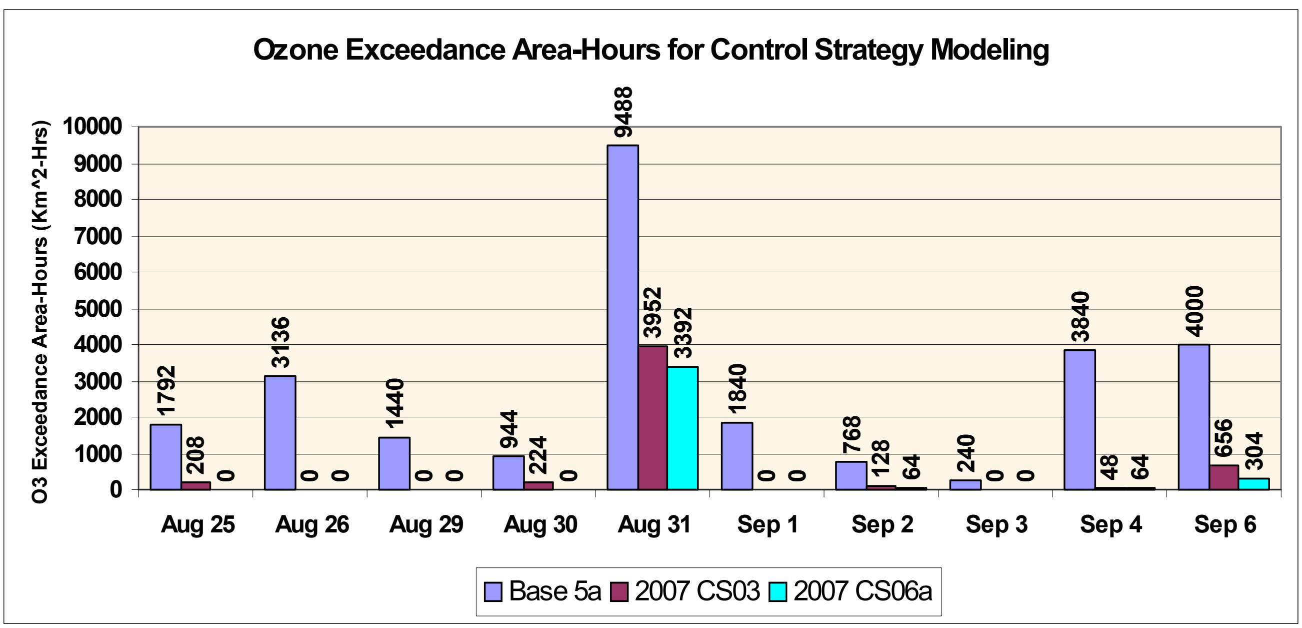


Figure 3.9-23: Exceedance Area-Hours-ppb for Base & Future Control Cases

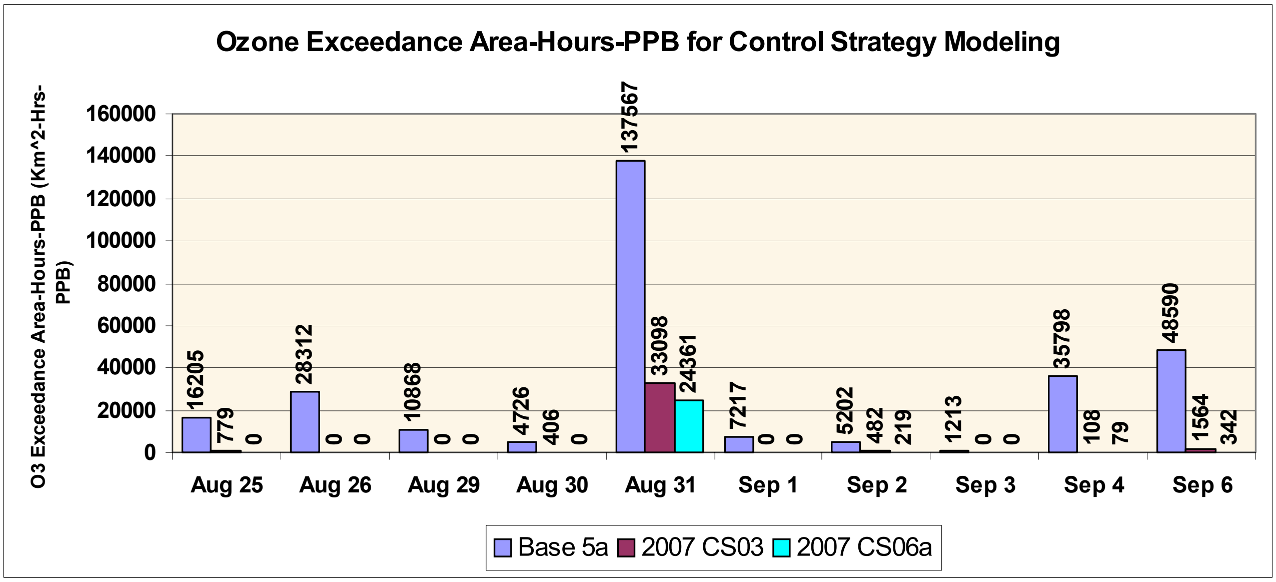


Figure 3.9-24: Peak modeled 1-hour ozone concentrations for CS-06a and CS-08

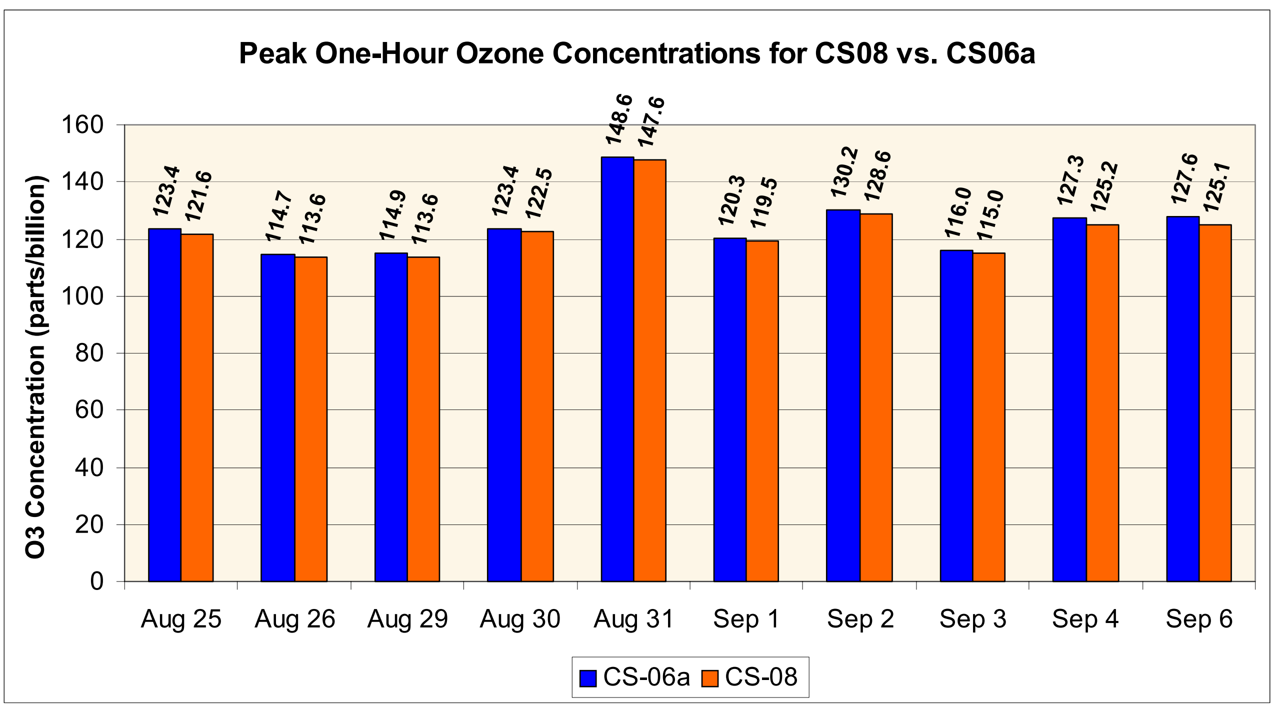


Figure 3.9-25: Modeled exceedance area for CS-06a and CS-08

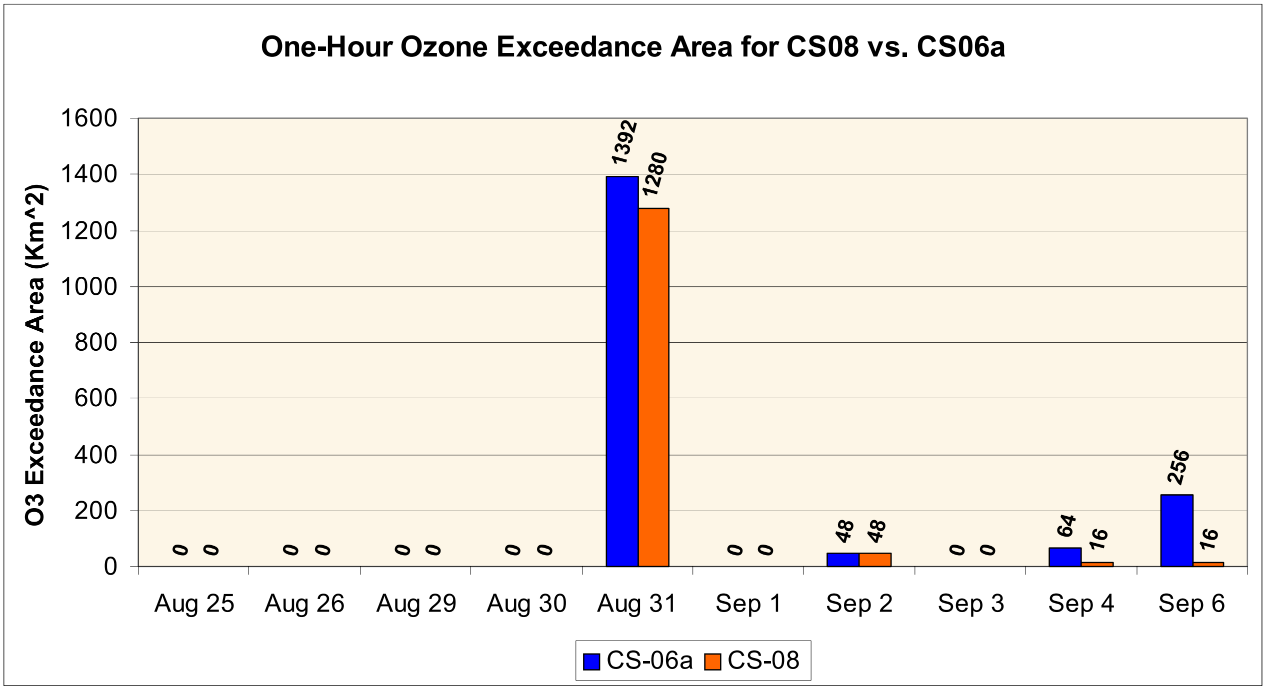


Figure 3.9-26: Modeled 1-hour exceedance area-hours for CS-06a and CS-08.

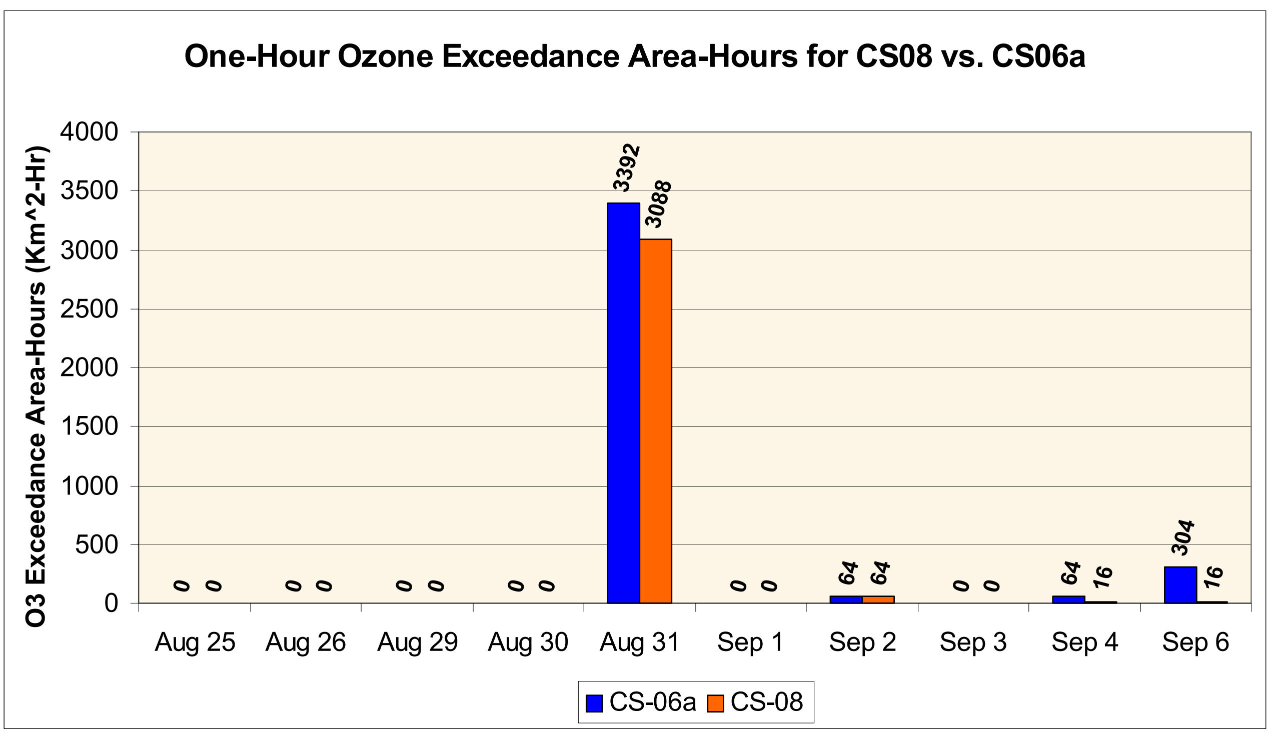
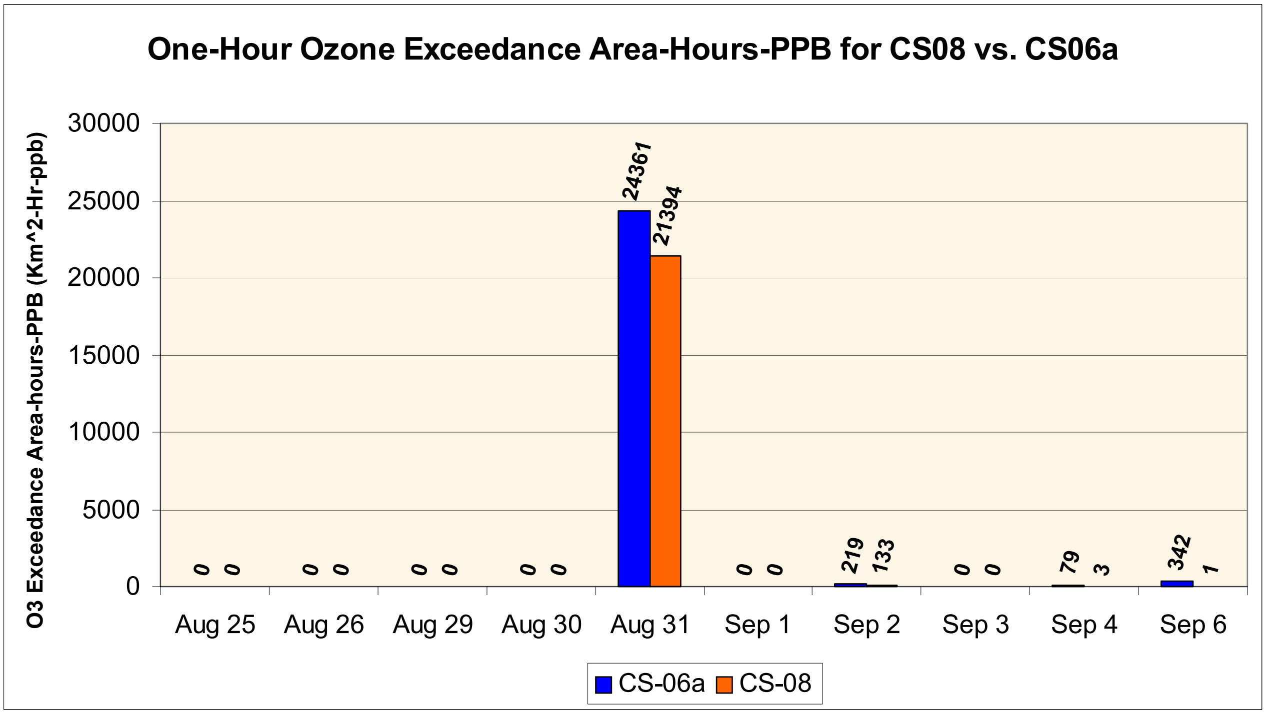


Figure 3.9-27: Modeled 1-hour exceedance area-hours-ppb for CS-06a and CS-08.

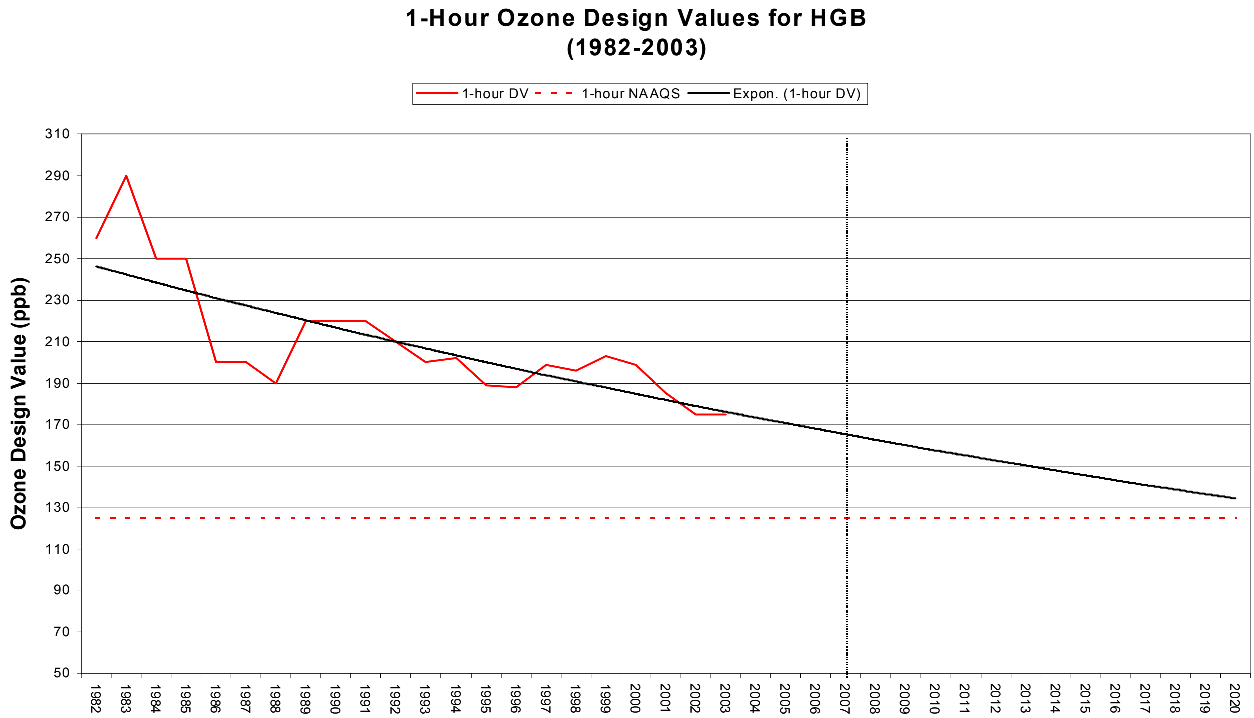


A glance at the above figures illustrates the tremendous improvements in overall air quality expected under the proposed control strategy. Except for August 31, the area of exceedance is reduced to zero or a very small geographic area throughout the episode. Area-hours shows an even more dramatic reduction, and the final exposure metric (area-hours-ppb) shows enormous reductions relative to the base case. Even on August 31, this last metric is reduced by over 84 percent with CS-08, and is reduced between 97 percent and 100 percent on the remaining days.

3.9.4 Ambient Trends

The 1-hour ozone design values for the HGB area have decreased significantly from 260 ppb in 1982 to 175 ppb in 2003. Using all this data to estimate a trend leads to the conclusion that attainment of the 1-hour ozone standard would be reached sometime after 2020 (see Figure 3.9-28, *Estimated Ozone Attainment Date Based on Ambient Data*). But examination of the figure shows that the area's design value dropped significantly during the 1980s, then flattened out during the 1990s, hovering around 200 ppb. Starting in the late 1990s, however, an encouraging trend appears to be emerging. Recently, design values have again resumed their downward trend and are at the lowest values seen in at least the last twenty years. The current trend may be partly due to meteorological conditions in recent years, but is almost certainly accelerated by emission reductions made since the 2000 SIP revision. If the design value continues to drop at a rate comparable to that seen in the most recent five-year period, then attainment may occur sometime around 2010. But the amount of emissions reductions is expected to increase each year until 2007 as a result of rules adopted in the 2000 SIP revision and in this SIP revision. Consequently, the design values are expected to decrease more rapidly as 2007 approaches. While this simplistic analysis alone by no means proves the area will attain the standard by 2007, the recent design value trends are consistent with reaching attainment sometime around 2007.

Figure 3.9-28: Estimated Ozone Attainment Date based on Ambient Data



3.9.5 Alternative Design Value

Traditional photochemical modeling can adequately replicate the routine emissions of a large industrial base located in an urban core with mobile source emissions typical of a large city. Traditional modeling cannot, however, replicate ozone produced by the sudden sharp increases in HRVOC emissions that occur in the HGB area. This technical deficiency provides an explanation for why the model's peak simulated ozone concentrations were all below the HGB area's design value in 2000. The actual design value calculated for the years 1999-2001 was 182 ppb, while Base 5b simulated peak ozone concentrations below 160 ppb on every day but August 31. The influence from short-term releases must be removed from the area's design value to determine whether the model is adequately simulating the routine urban ozone formation in the base case. The model would perform adequately if the simulated ozone peak concentrations were consistent with this alternate design value.

The TCEQ approximated removing the influence of short-term releases using a method developed by Blanchard (2001). The Blanchard method calculates a design value that excludes the effects of sudden large increases in observed ozone concentrations. Blanchard used a threshold of a 40 ppb rise in ozone concentration in one hour to distinguish sudden rises from the more typical case where ozone increases more gradually.

To apply Blanchard's technique to the year 2000, the TCEQ used 1-hour average ozone data for the HGB area from EPA's, Aerometric Information Retrieval System (AIRS) from years of 1999 through 2001. The hour-to-hour difference was calculated for each of the 16 ozone monitors in the HGB area. If the difference for any monitor for a given day was greater than 40 ppb, the day was determined to be characterized by a sudden ozone concentration increase (SOCI)[2].

Once a day has been identified to contain a SOCI, that day was removed from the calculation of the design value. The alternate (non-SOCI) design value was determined by removing all days with identified SOCIs and recalculating the design value. The alternate design value so calculated is 144 ppb. Base 5b includes seven days with modeled peak ozone greater than 144 ppb, so the modeled peaks in fact represent very well the (non-SOCI) design value. If SOCIs result primarily from emission events[3], then it follows that the model is over-predicting the "routine" part of the ozone on these days, so the future concentrations would actually be lower than reported for CS-08.

3.9.6 Addressing Short-Term Excursions

Unlike the base case, the future case modeling includes only limited variation in point source emissions (primarily temperature-driven variability in electric generation). Variation rising from the Special Inventory is not applied in future case modeling. But there is certain to be some level of variability in the future emissions, and this revision includes a short-term cap on point source HRVOC emissions to address this issue.

In Section 3.8, major findings of a study conducted by Dr. Allen et al. which establishes a relationship between the levels of short-term releases and the expected effects on peak ozone concentrations have been provided. The report states that "At the most sensitive locations, at the most sensitive times of day, releases over approximately a two to three hour period can lead to increases of 2 to3 ppb in peak ozone concentration per 1000 lb of additional HRVOC emissions." (The "most sensitive locations" and "most sensitive times of day" can vary depending upon meteorological conditions and upon variations among non point source emissions). Based upon an analysis of the TCEQ database on event emissions, short-term releases of a magnitude to impact peak ozone are not seen to occur in time periods greater than an hour. Of those that occur at levels greater than 1000 lb, over 85 percent occur at rates less than 40 minutes. Due to the linear nature of the results, this would suggest an event of 1500 lbs would have an impact on peak ozone equivalent to the impact of 1000 lbs over an hour. Dr. Allen also concluded that if actions are taken to reduce emission variability, however, the magnitude of the emission variability that should be expected upwind of the peak, region wide ozone concentrations could be decreased.

The report by Allen et al. also finds that a release of 1000 pounds/hr at the "right place and right time" is expected to occur only about once per year based on reported emission events. The full report shows that the frequency of release decreases with increasing magnitude, so the probability of one of the episode days being affected by a larger release is even lower.

However, since smaller releases occur fairly frequently, there is a good possibility that one or more days would be affected to a lesser extent. This revision includes a short-term cap of 1200 lbs/hour which is consistent with a modest increase in peak ozone over the CS-08 modeled peaks. This emission specification is a limit that is sufficiently low to reduce the likelihood that a sudden emissions increase will

---

[2]Blanchard called these sudden ozone increases Transient High Ozone Events (THOEs), but this label is somewhat misleading since some of the events persist for several hours, hence are not "transient".

[3]Sudden ozone increases have been observed in many cases to result from identified emission events, although there may be cases where rapid ozone rise is triggered by meteorological phenomena.

occur under the right conditions and be of sufficient magnitude to cause a 1-hour ozone standard exceedance.

3.9.7 Future-case sensitivity analyses of adjustments to Other VOCs (OVOCs)

Several commenters asked the TCEQ to consider the affects of adjusting OVOCs (reactive VOCs other than HRVOCs) on the 2007 attainment demonstration. This section was added in response to their comments.

3.9.7.1 Background

The TCEQ is and has always been highly reluctant to make any inventory adjustments which could be viewed as arbitrary for attainment demonstration purposes. Adjusting model inputs without adequate justification, especially for purposes of improving base-case model performance, is called "tuning" and is largely discredited in the air quality modeling community. Tuning is likely to cause the model to get the right answer for the wrong reason and may lead to adoption of costly, ineffective control strategies.

On the other hand, perturbing model inputs to measure the effects on model output is a common accepted modeling practice. This practice, called *sensitivity analysis*, is used to help identify likely causes of poor model performance and to suggest solutions. Sensitivity analyses are often used in future-case modeling to help find the preferred path to attainment and to test the effectiveness of control strategies under alternative modeling assumptions.

The TCEQ has for many years used sensitivity analyses to help identify the most critical inputs to the model, and has employed a wide variety of techniques to compare ambient data with emissions inventories to identify discrepancies. Traditionally, results of these studies have been used to allocate resources for bottom-up inventory improvement projects, including studies of construction equipment, shipping, recreational boating, and many others including several biogenic emissions projects. The results of these projects have then been incorporated into the modeling inventories.

The TexAQS 2000 results identified a discrepancy between the emissions of terminal olefins and ambient concentrations of these chemicals, as has been documented in peer-reviewed scientific papers (Karl, 2003; Wert, 2003) and in numerous project reports (e.g. Estes et al, 2002; Roberts et al, 2004; Yarwood et al, 2004). As a result of these analyses, the TCEQ has undertaken a number of bottom-up research projects to improve emission estimates from industrial sources of these chemicals. For emissions of terminal olefins in the HGB area only, there is sufficient evidence to support applying an adjustment factor.

Some evidence suggests that OVOCs may be under-estimated in the modeling inventory, but the evidence to justify adjusting emissions of OVOCs is much less conclusive. To date, few in-depth analyses of aircraft observations have been conducted comparing OVOC concentrations with those expected based on the reported emissions (although several projects are expected to be completed within the next year). One such study was conducted by the TCEQ (see Appendix B.5 and B.6), in accordance with the Future Directions decided in the December 2002 SIP revision. This study compared ambient concentrations of OVOCs at the Clinton Drive and Deer Park monitoring locations with the reported industrial inventories in the vicinity of the respective monitoring locations. The study suggested that OVOCs may be under-reported by a factor of 4.8. The scope of this study was limited, however, because only these two sites have collected continuous, multi-year speciated hydrocarbon data in the Ship Channel industrial district.

Because of the limited analysis available, the TCEQ concluded that including any adjustments to the OVOC emissions in its control strategy evaluation at this time would be premature. Instead, the commission used the results of the in-house study to conduct a base-case sensitivity modeling analysis reported previously in Appendix B (Model Performance Evaluation). This analysis indicated that the adjustment applied to the OVOCs (combined with the adjustment already applied to the HRVOCs) apparently created too much reactivity in the model resulting in model performance degradation.

3.9.7.2 Sensitivity Analyses

After the current SIP revision was proposed in June 2004, the commission conducted additional sensitivity modeling which considered the effects of adjusting the future-case OVOC emissions by the same 4.8 factor used in the base-case sensitivity analysis. Results of this analysis suggest that, if the OVOC emissions adjustment more accurately represents OVOC emissions, then additional reductions of OVOCs may be necessary. In fact, a second sensitivity analysis which applied the HRVOC reductions of strategy CS-06a to the adjusted OVOCs (along with the HRVOCs) produced peak 1-hour ozone concentrations for all days except for August 31 that are below (6 of the remaining 9 days), or just above (3 of the remaining 9 days), the NAAQS. Results of these sensitivity analyses are shown graphically in Figure 3.9-29, *Modeled 1-hour Peak Ozone for Base Case, Future Control Case CS-06a, and Future Control Case with Reductions to All Reactive VOCs, Adjusted OVOC Emissions*, below. For comparison, the results of the modeling without adjustment to the OVOCs are shown in Figure3.9-30, *Modeled 1-hour Peak Ozone for Base Case and Future Control Case CS-06a, No Adjustments to OVOC Emissions*.

The analysis was run using CS-06a instead of the new future control case CS-08. The TCEQ did not re-run this analysis since the changes between CS-06a and CS-08 were relatively minor and would not change the conclusions.

Figure 3.9-29: Modeled 1-hour peak ozone for base case, future control case CS-06a, and future control case with reductions to all reactive VOCs, adjusted OVOC emissions.

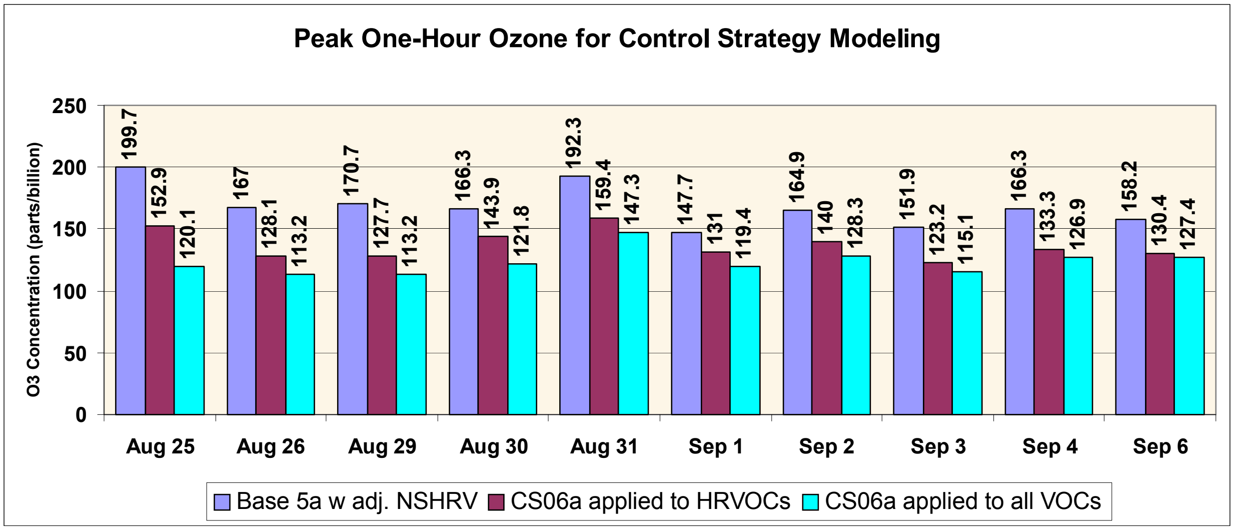
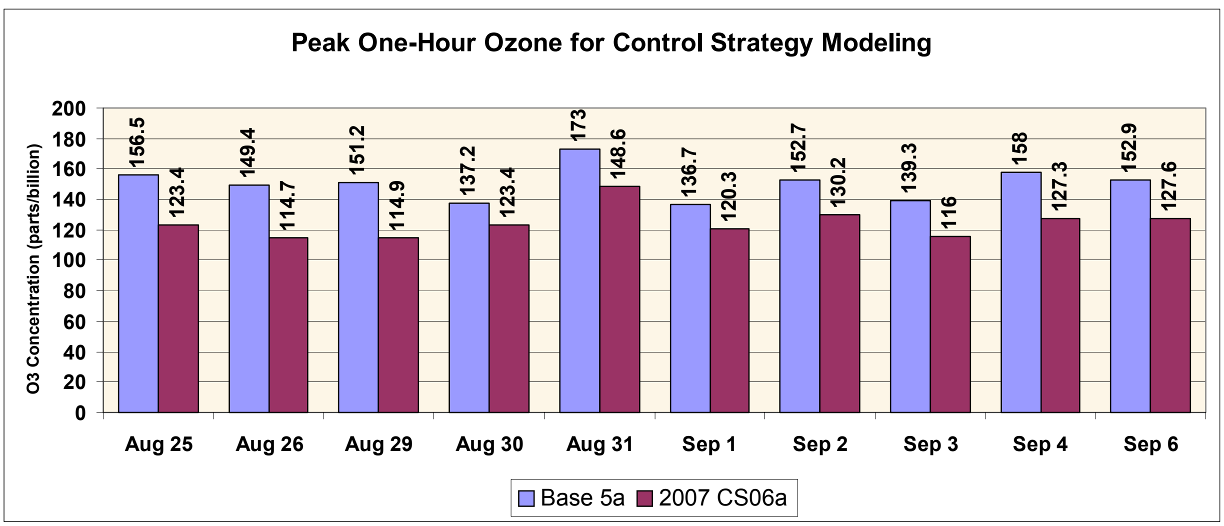


Figure 3.9-30: Modeled 1-hour peak ozone for base case and future control case CS-06a, no adjustments to OVOC emissions.



Comparing the values associated with the leftmost (blue) bars between the two figures shows the effects on the base case peak modeled ozone concentrations of adjusting the OVOCs. For example, the modeled August 25 peak increased from 157 ppb to 200 ppb due to the OVOC adjustment. These results are also reported in Appendix B.

Comparing the values associated with the maroon bars (center in Figure 3.9-29, rightmost in Figure 3.9-30) shows the effects of the OVOC adjustment on the future case modeled peaks. For example, on August 25, the future modeled peak increases from 123 ppb to 153 ppb.

Finally, the values associated with the rightmost (aqua) bar in the top graph show the effects of applying the CS-06a reductions to all reactive VOCs instead of only HRVOCs. The results show future ozone concentrations that are near attainment or better on all days except August 31. The results presented in Figures 3.9-29 and 3.9-30 reflect the model configuration of the June 2004 proposal and not the new CS-08 future control case. Since the conclusions of the analysis reported here would remain valid if the modeling were re-run using the "best" cases, the TCEQ did not re-run these sensitivities. If the modeling were re-run using CS-08, peak ozone concentrations in the future cases would be expected to drop by one or two ppb.

3.9.7.3 Summary

The sensitivity analyses described in this section show that if OVOC emissions are indeed under-estimated in the current attainment demonstration, then reductions to these emissions may be required in addition to those already adopted for HRVOCs. However, the base case sensitivity analyses documented in Appendix B show that the adjustment applied may add too much reactivity to the model and may not be appropriate. The case for adjusting the OVOC emissions is not supported by a large body of peer-reviewed literature, so any adjustments at this time would be speculative. Therefore, while the results of the sensitivity analyses presented in this section are informative, they are not supported, to the extent that it is appropriate, for inclusion in the attainment demonstration modeling.

The TCEQ is actively addressing the issue of OVOC emissions and is sponsoring and/or participating in several studies to attempt to better define their role in ozone formation in the HGB area. These studies are listed in a new section at the end of this chapter titled "Future Directions."

3.9.8 Wildfires

As was discussed in Section 3.7.2, the latest future control case CS-08 does not include the exceptionally large wildfire emissions recorded in early September 2000. Although such events are quite rare, it is conceivable that similar wildfire activity could occur at some future date. This section presents a comparison of the predicted peak ozone concentrations with and without wildfire emissions.

Table 3.9-3: Peak 2007 modeled ozone concentrations in HGB for CS-08, with and without wildfires.

Episode Day	Modeled Peak Ozone Concentration (ppb)	
	CS-08 without wildfires	CS-08 with wildfires
August 25	121.6	121.6
August 26	113.6	113.6
August 29	113.6	113.6
August 30	122.5	122.5
August 31	147.6	147.7
September 1	119.5	119.6
September 2	128.6	128.7
September 3	115.0	115.1
September 4	125.2	126.3
September 6	125.1	126.8

The table shows very similar ozone concentrations when CS-08 is run with and without fires. The notable differences are on September 4 and 6, where the exceptional wildfire activity added about 1 ppb to the modeled peak on the former and about 2 ppb on the latter.

3.10 8-HOUR OZONE NON-INTERFERENCE DEMONSTRATION

Because this SIP revision includes elements that modify certain previously-adopted rules, EPA requires a demonstration showing that the current strategy will not interfere with attainment of the 8-hour ozone standard. This non-interference demonstration is an independent requirement in § 110(l) of the Federal Clean Air Act, which requires that any plan revision must not interfere with any applicable requirement concerning attainment and reasonable further progress or any other applicable requirement of the Act 42 U.S. C. § 7410(l). To determine whether this SIP revision would interfere with any applicable requirement, the commission conducted non-interference modeling, specifically to determine whether this revision would interfere with attainment of the 8-hour ozone national ambient air quality standard. The modeling shows that the current strategy is equivalent or superior to the strategy in the federally approved December 2000 and September 2001 SIP revisions.

The TCEQ worked with EPA Region 6 to determine the most appropriate measures to use for 8-hour ozone modeling since EPA has not yet issued Final Guidance on assessing 8-hour ozone performance. A very detailed performance evaluation of the modeling is provided in this SIP revision, both for 1-hour and 8-hour ozone prediction. According to guidance received from EPA, equivalence can be demonstrated by showing that the new strategy will not create higher 8-hour ozone levels than the old strategy by showing that it will not create more 8-hour ozone exceedances, higher 8-hour ozone concentrations, or higher cumulative exposure levels than the old strategy. The first criterion, number of ozone exceedances, is met since both strategies have 8-hour ozone peaks greater than 85 ppb on all ten days. The second criterion, level of ozone exceedances, clearly favors the new strategy with lower 8-hour ozone peaks on nine of ten days. The third, cumulative exposure, also favors the new strategy on nine days out of ten.

This demonstration must also show whether the total collection of strategies in CS-2000 is equivalent in ozone reduction effectiveness to the total collection of strategies in CS-06a. Therefore, the most recent and best available information was used in developing the inventories for comparing CS-2000 and CS-06a so that a proper comparison can be made.

For the non-interference demonstration, all rules that were identified as "gap" measures in the December 2000 and September 2001 SIP revisions were modeled. Reductions associated with some measures changed as a result of improving the underlying inventory. It is more appropriate to evaluate the identified measures relative to the best currently available inventory rather than evaluate them with an obsolete inventory. EPA Region 6 informed the TCEQ that it was not necessary to adjust the unidentified portions of the "gap" to compensate for changes occurring as a result of inventory improvements. Therefore the "gap" modeled in the CS-2000 (and in the new CS-2001) cases remains at 56 tpd.

Consequently, the TCEQ focused on quantifying the magnitude of the CS-2000 control strategy benefits using currently available data and inputs. It is certainly unrealistic to expect that the magnitude of NO_x and VOC control strategy benefits based on the December 2000 SIP strategies (particularly those calculated with MOBILE5 and a different set of activity data) were going to match updated estimates based on newer activity data and emission estimation tools (such as MOBILE6.2 and updated activity data).

One of the key issues of concern in conducting this demonstration was the fact that the photochemical modeling is now based on a vastly improved August-September 2000 ozone episode rather than the outdated September 1993 ozone episode, which was last utilized for the December 2000 SIP. Recognizing that this was a major change from 2000, the non-interference modeling included the control strategies listed in the December 2000 SIP together with updated inventories and updated methodologies. This was incorporated into a 2007 future case inventory projection of the new August-September 2000 ozone episode. This inventory was labeled CS-2000. The alternative would have been to model CS-2000 with old inventories and old methodologies or a combination of either new inventories and old methodologies or old inventories and new methodologies. Such approaches would be impractical and meaningless.

The benchmark for this demonstration is the attainment demonstration SIP revision adopted by the commission on September 26, 2001, and approved by EPA on November 14, 2001. Unfortunately, the modeling conducted for that SIP did not have the benefit of the TexAQS 2000, hence the inventory modeled is likely substantially deficient in emissions of HRVOCs. Thus, directly comparing the current modeling to the modeling in the December 2000 and September 2001 SIP revisions is meaningless. Instead, the final control strategy from the 2001 SIP revision was applied to the current future case, including the HRVOC adjustment, to provide a fair comparison.

Before performing any modeling analysis for 8-hour ozone, the TCEQ conducted extensive analysis of the model's ability to reproduce observed 8-hour ozone concentrations. This analysis is detailed in Appendix B, "Model Performance Evaluation." Overall, the model simulates 8-hour peak ozone concentrations very well, so it is suitable for evaluating control strategies relative to the new 8-hour ozone standard. In particular, Appendix B includes a large number of scatter plots (by monitor, by day, and overall), a bias calculation, and 8-hour ozone isopleths along with analysis and interpretation. This thorough analysis provides appropriate information to understand the uncertainty of the 8-hour ozone projections and RRFs estimated. The TCEQ has evaluated most of the performance metrics suggested in EPA's Draft Guidance for the use of models and other analyses in attainment demonstration for 8-hour ozone NAAQS and selected the ones most appropriate for unambiguously interpreting and presenting model performance. A second issue arises from the nature of the 8-hour ozone attainment test, which is based on relative reductions near monitoring sites. Because monitors cover only a subset of the modeling domain, there may be unmonitored ozone hot spots where high concentrations of ozone frequently occur. If such hot spots occur, then any non-interference assessment would have to account for these areas in addition to the relative reductions at the monitors. Using the Screening Test detailed in the EPA Draft 8-hour modeling guidance (EPA, 1999), the TCEQ evaluated the CS-08 modeled ozone concentrations for hot spots, and found that none occurred. Thus, comparisons between CS-08 and any other control strategy can be made without concern about potential ozone hot spots.

EPA Region 6 provided guidance in an undated memo in March 2004 explaining how the non-interference demonstration should proceed. As a result, the current modeling setup, including the adjusted HRVOC emissions, was modified to reflect the rules adopted in December 2000 and September 2001 SIP revisions. The strategy developed to mimic the control strategy in the approved SIP is called CS-2001. In CS-2001, the current “80 percent” Point Source NO_x reductions were replaced with the original “90 percent” Point Source NO_x reductions and the HRVOC controls were not applied. All remaining reductions included in the 2001 attainment demonstration were applied to CS-2001 except for reductions due to energy efficiency measures. Because energy efficiency related reductions are very difficult to allocate spatially, they were not modeled explicitly as part of this attainment demonstration. So for purposes of this comparison, energy efficiency was omitted from both control packages. The differences between CS-2001 and the current control strategy (CS-08) are listed in Table 3.10.1, *Comparison of the 2001 Control Strategy (CS-2001) with Current Control Strategy (CS-08)* .

The CS-2001 strategy was then run and several 8-hour ozone metrics recommended in the EPA Region 6 memo were calculated. Table 3.10-2, *Relative Reduction Factors and Future Design Values by Monitor for CS-08 and CS-2001*, shows that CS-08 is slightly more beneficial than CS-2001 in both average relative reduction factor (0.931 vs. 0.940) and in future design value (107 vs. 108 ppb), even though some stations fare slightly worse under the new control strategy. Figure 3.10-1, *Peak 8-Hour Ozone Concentrations for Strategies CS-2001 and CS-08*, shows peak 8-hour ozone concentration on each episode day, Figure 3.10-2 , *8-Hour Exceedances Area for Strategies CS-2001 and CS-08*, shows area of exceedance, and Figure 3.10-3, *8-Hour Ozone Exposure for Strategies CS-2001 and CS-08*, shows ozone exposure, which is the area of exceedance weighted by the 8-hour ozone concentration in each grid cell, more specifically, by the amount the modeled ozone concentrations exceed the 8-hour ozone standard. For both peak 8-hour ozone concentration and exposure metrics, benefits of the new strategy exceed those of the old on every day except September 6, where the old strategy is slightly better. For area of exceedance, however, the comparison is much less clear-cut. The older strategy shows more of a benefit on 6 of 10 days and the new strategy shows a greater benefit on 3 days. Both strategies indicate the same benefit on 1 day.

Table 3.10-1: Comparison of the 2001 control strategy (CS-2001) with current control strategy (CS-08)

Model Run	CS-2001	CS-08
Point Source Reductions		
"90%" NO_X reduction	X	
"80%" NO_X reduction		X
64% HRVOC reduction		X
20 tpd additional HRVOC reduction in Harris County		X
Onroad Mobile Source Reductions		
8-County I/M	X	

5-County I/M		X
Vehicle Idling Restrictions	X	
Texas Low Emission Diesel (TxLED)	X	X
VMEP (10.4 tpd NO_X)	X	
VMEP (3.6 tpd NO_X)		X
TERP (14 tpd NO_X)		X
TCMs	X	X
55 MPH speed limit	X	
65 MPH speed limit		X
Area/Nonroad Mobile Source Reductions		
TERP (18.9 tpd)	X	
TERP (24.9 tpd)		X
Lawn & garden operating restrictions	X	
Clean Diesel	X	X
VMEP (12.6 tpd NO_X)	X	
VMEP (3.4 tpd NO_X)		X
Small gas-fired boiler, water heater reductions	X	X
Cal Spark-ignition rules	X	X
Clean Gas Cans		X
Airport ground support equipment	X	X
Small stationary diesel engines	X	X
"Gap" measures		
Nonspecific NO_X reductions (56.0 tpd)	X	
Regional (TX) rules		
Clean Gasoline	X	X
Clean Diesel	X	X
Clean gas cans		X
Senate Bill 7	X	X
Cal Spark ignition	X	X

Although not quantified, decreasing emissions of HRVOCs also results in the decrease of secondary formation of reactive aldehydes, including formaldehyde. Reductions in aldehydes serve to decrease the total airmass reactivity, and consequently, ozone formation potential. Reducing formaldehyde concentrations also has the beneficial effect of decreasing public exposure to a substance which on its own has the potential to irritate the eyes and respiratory tract, and which has been classified by EPA as a probable human carcinogen.

Over all, CS-08 provides more air quality benefits than CS-2001, since it provides reductions in both average relative reduction factors and future design values, and reduces peak 8-hour ozone levels and total exposure. Therefore, based on the guidance received from EPA Region 6, the non-interference test is passed.

Table 3.10-2: Relative Reduction Factors and Future Design Values by Monitor for CS-08 and CS-2001

Site	Relative Reduction Factor			Future Design Value	
	CS-08	**CS-2001**	**Relative Difference**	**CS-08**	**CS-2001**
BAYP	0.980	0.983	-0.31%	107	108
C35C	0.978	1.054	-7.21%	93	101
CLTA	0.932	0.924	0.87%	84	84
CONR	0.831	0.802	3.62%	75	72
DRPK	0.923	0.995	-7.24%	99	107
GALC	0.951	0.934	1.82%	93	91
HALC	0.886	0.872	1.61%	95	94
HCQA	0.930	0.919	1.20%	92	90
HLAA	0.933	0.920	1.41%	72	71
HNWA	0.882	0.856	3.04%	92	89
HOEA	0.917	0.977	-6.14%	94	100
HROC	0.982	1.036	-5.21%	92	97
HSMA	0.911	0.907	0.44%	81	81
HWAA	0.885	0.888	-0.34%	76	76
SHWH	1.027	1.038	-1.06%	89	90
TLMC	0.944	0.936	0.85%	86	85
Average	0.931	0.940	-0.99%		
Max				107	108

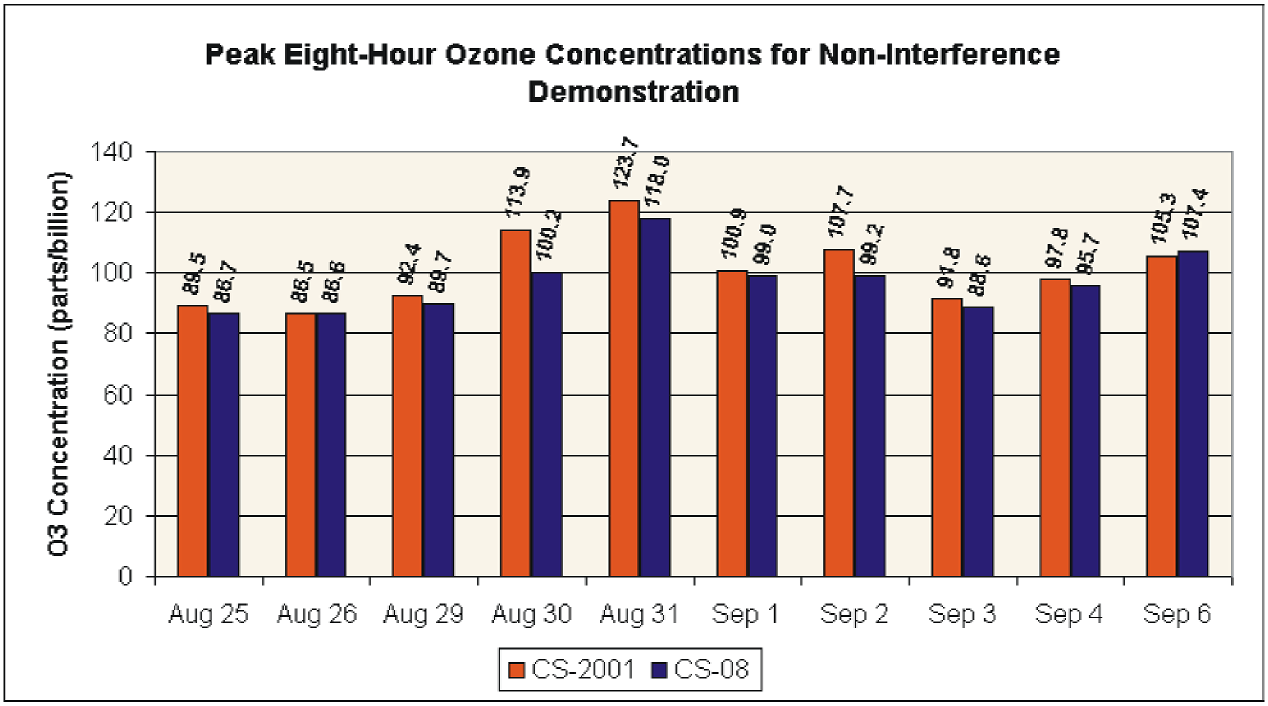


Figure 3.10-1: Peak 8-Hour Ozone Concentrations for Strategies CS-2001 and CS-08

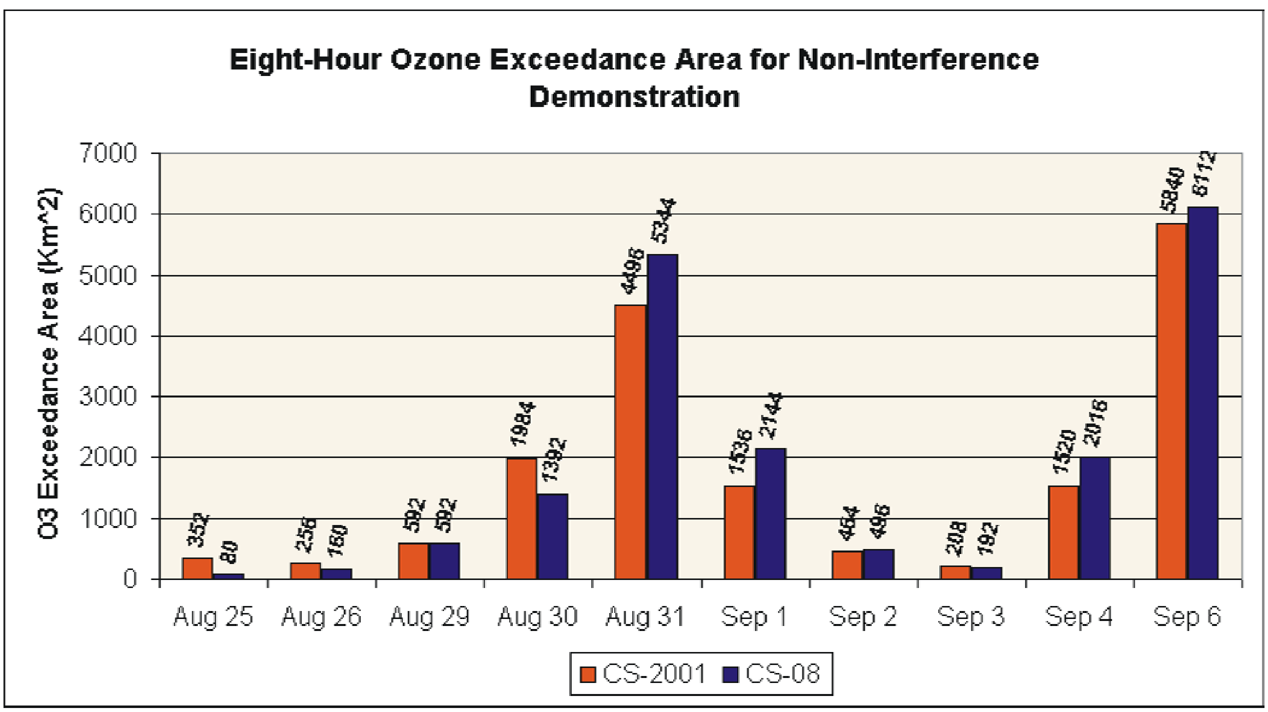


Figure 3.10-2: 8-Hour Exceedance Area for Strategies CS-2001 and CS-08

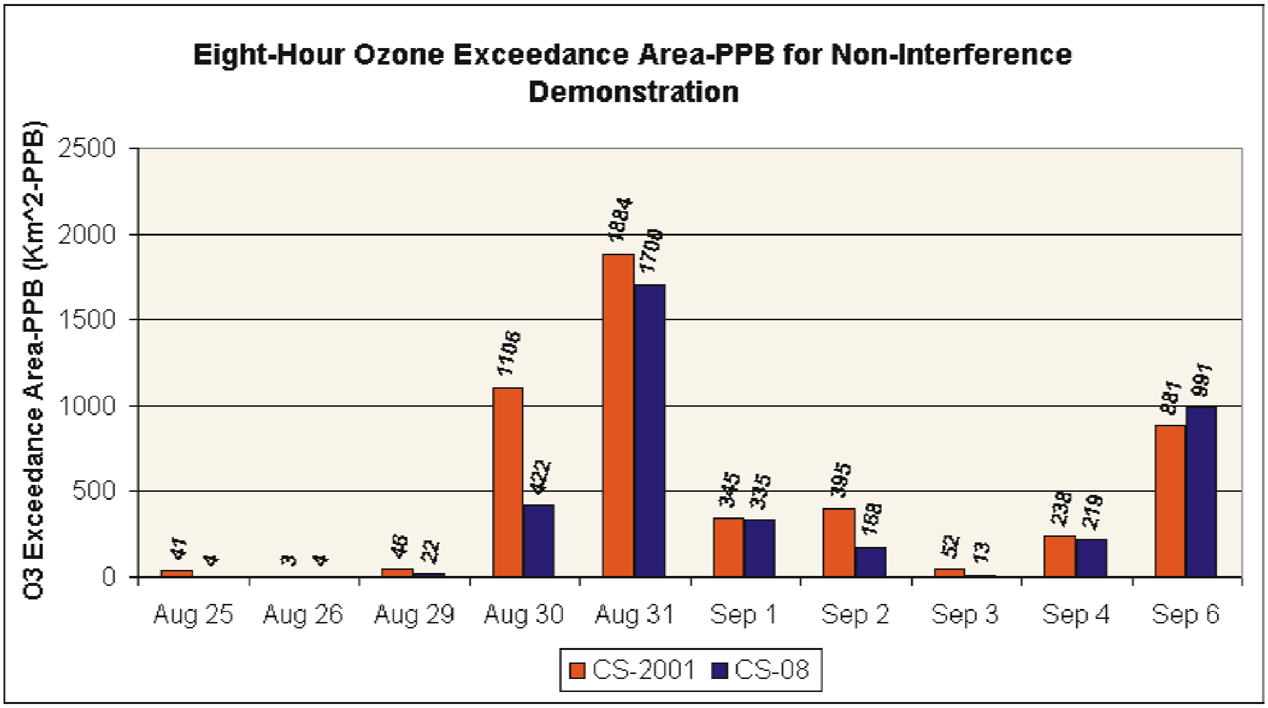


Figure 3.10-3: 8-Hour Ozone Exposure for Strategies CS-2001 and CS-08

3.11 SUMMARY AND CONCLUSIONS

In this attainment demonstration an episode spanning from August 18 - September 6, 2000, which includes the episode modeled in the December 2002 SIP Revision, was modeled. A new meteorological characterization incorporating GOES satellite data for part of the episode from August 22-September 1 and standard MM5 modeling for the remainder of the episode was used. The GOES-based meteorology represents a significant advance in the ability to simulate the complex wind fields seen in the HGB area, and its use will likely be expanded in the near future to include the remainder of the episode.

A substantially improved modeling inventory was developed and incorporated many new and improved emission characterizations including better hydrocarbon speciation, emissions from wild fires, and updated point, area, and mobile source emissions. As was the case in the 2002 SIP revision, emissions of HRVOCs were increased in the base case in accordance with the TexAQS 2000 findings.

Model performance for August 18-21 was unacceptable, and that part of the episode will not be used until an improved meteorological characterization can be developed. Model performance for the remainder of the episode generally ranged from acceptable to very good, with the notable exception of September 5 where the model failed to accurately replicate observed ozone concentrations. The model under-predicted peak concentrations on August 30, as was the case in the 2002 SIP revision. This underprediction may be due to significant emissions not represented in the modeling inventory for this day. The 8-hour ozone performance metrics were calculated, and the model appears to represent peak 8-hour ozone concentrations reasonably well.

Future case modeling was conducted by first applying growth to the base case inventory, then applying the controls used in the 2002 SIP revision with some modifications. When this future case was run, additional reductions were needed and a new control strategy, CS-06a was developed. This strategy reduced emissions of HRVOCs in Harris County beyond the levels established in the 2002 SIP revision and brought the modeled ozone concentrations near or below the 1-hour ozone standard on all days but August 31. Extensive analysis of August 31 showed the day represents an exceedingly unusual meteorological regime which has only occurred twice in the past 57 years. Because this type of meteorology is so rare, it would not be appropriate to allow it to drive control requirements vastly more restrictive than those required for all the other episode days.

Subsequent to the June proposal of this SIP revision, several minor enhancements and corrections were incorporated into the future control case, and a new future control case, called CS-08 was developed. Some analyses were re-done using the new future case, but those reported using CS-06a remain valid because of the relatively minor differences between CS-06a and CS-08.

Additional Weight-of-Evidence analyses indicate that 2007 air quality will likely be substantially better than predicted with CS-06a and CS-08. This evidence includes a suite of expected, but difficult to quantify, emission reductions in the area, including benefits collateral VOC reductions, which will no doubt occur as a side benefit of the HRVOC rules adopted in this SIP revision.

Modeling was conducted by a group of independent researchers to investigate the effects of emissions events on air quality in the region. This work led to the establishment of a short-term cap limiting the effects of these events on peak ozone concentrations.

Finally, modeling conducted shows that the current control strategy will not interfere with the region's ability to meet the 8-hour ozone standard.

In conclusion, a strategy has been developed that will demonstrate attainment of the 1-hour ozone standard in the HGB area by 2007. The new controls will reduce emissions of HRVOCs, shown by the TexAQS 2000 to be a notable contributor to the very high observed ozone concentrations frequently observed in the area. This strategy can be expected to bring the area into compliance with the 1-hour ozone standard without interfering with the area's ability to attain the 8-hour ozone standard in the future.

3.12 FUTURE DIRECTIONS

The TCEQ is continuing to develop a more complete, accurate characterization of ozone formation in the HGB area, as well as in the remainder of Texas. First and foremost is the 2005-6 Texas Air Quality Study follow-on, TexAQS II. This study will continue to examine the unique features of the Texas Gulf Coast and will collect volumes of data designed to address questions not completely answered during the original TexAQS 2000. The TexAQS II will expand upon the geographical scope of the TexAQS 2000 and will focus on essentially all of Eastern Texas, including DFW, BPA, Austin, San Antonio, and Tyler/Longview/Marshall. A large number of studies will be conducted in each of the following areas:

- Transport of pollutants into and out of Texas
- Emissions inventories
- Meteorological issues
- Atmospheric chemistry

The TexAQS II Science Plan contains a detailed discussion of these and other issues. The plan can be found at http://www.tnrcc.state.tx.us/air/aqp/airquality_techcom.html#topic2b3.

Because the TexAQS II results will not be available until 2007 at the earliest, it will not be possible to incorporate the improved scientific understanding into modeling for the 2007 8-hour ozone attainment SIPs required for HGB and DFW, although it is hoped that some early results may be helpful in corroborating the modeling assumptions. For the next round of SIPs, the TCEQ plans to investigate several possible improvements to the modeling process, including:

- *Emissions inventory performance evaluation*. The recently-available data from the Enhanced Industry Sponsored Monitoring (EISM) provides a very comprehensive set of hydrocarbon measurements in and around the Houston Ship Channel and near several smaller industrial clusters in the HGB area. These data are currently being analyzed by the Pacific Northwest National Laboratories and will be compared with reported emissions inventories. Analyses will be performed for both HRVOCs and OVOCs. The EISM data will provide a rich data set for a number of additional analyses in the near future.

- *Improved biogenic emissions*. New land-use data collected by the Texas Forest Service provides an opportunity to significantly enhance the biogenic emission estimation in the HGB area. The TCEQ also plans to continue evaluating drought and heat-stress models for possible use in estimating biogenic emissions.

- *GOES data assimilation*. The TCEQ has acquired processed GOES data for the entire extended episode and will test revised meteorological characterizations for this period. The TCEQ has also created a path for acquiring additional GOES data in a format suitable for modeling, so it can be used if additional episodes are chosen for the 2007 SIP revisions.

- *Continued improvements to the emissions inventory*. Several current or planned projects will help the TCEQ to continue to improve all aspects of its modeling inventory. Significant improvements are expected in locomotive emissions and offshore emissions in the near future.

- *Evaluation of Other VOCs.* Several ongoing efforts will provide additional information regarding the importance of OVOCs to ozone concentrations in the HGB area. In addition to the TCEQ modeling efforts, evaluation of OVOCs is a component of the H-12 modeling project. Also, as mentioned in Chapter 4, other VOCs data will be analyzed using different reactivity metrics to further delineate their contribution to ozone concentrations. Finally, results of an ongoing contract project performed by Pacific Northwest National Laboratory are expected to increase the understanding of the role OVOCs play in formation in the HGB area ozone.

- *SAPRC chemistry and CMAQ*. As part of its efforts to employ the most current, most scientifically sound modeling methodologies, the TCEQ will continue to investigate use of advanced modeling methods. The TCEQ is currently evaluating the Statewide Air Pollution Research Center (SAPRC) chemical mechanism and the Community Multiscale Air Quality (CMAQ) Modeling System for possible use in future SIP work.

The commission has a long history of supporting enhancements of air quality models and associated applications and input data. These endeavors are critical to supporting SIP development for Texas areas and will continue to be a top priority. The commission is committed to working in cooperation with the regulated community, academia, research consortiums, and others to ensure that the modeling used to develop effective control strategies will use the most current scientific methodologies and information to replicate high ozone episodes in a given area.

Because the level of scientific knowledge is constantly evolving, a comprehensive description of ongoing or planned research projects is not provided at this time. However, the TCEQ does maintain a catalog of projects relevant to Texas. The catalog is also available and maintained at http://www.tnrcc.state.tx.us/air/aqp/airquality_science.html.

3.13 ACCESSING MODELING DATA

All documentation and modeling input/output files generated as part of the Phase 2 MCR modeling will be archived. Dr. Jim Smith of the TCEQ is responsible for these products and may be reached by telephone at (512) 239-1941 or via e-mail, jismith@tceq.state.tx.us for information regarding data access or project documentation.

3.14 BIBLIOGRAPHY

Allen, D., C. Murphy, Y. Kimura, W. Vizuete, T. Edgar, H. Jeffries, B.-U. Kim, M. Webster and M. Symons, 2004. *Variable Industrial VOC Emissions and their impact on ozone formation in the Houston Galveston Area*. Texas Environmental Research Consortium Project H-13, prepared for Houston Advanced Research Center, The Woodlands, Texas, April 9, 2004.

Allen, D., Katamreddy, A., Junquera, V., Decabooter, J., 2002. *Emissions Inventory Associated with Forest, Grassland, and Agricultural Burning during the Texas Air Quality Study*, Texas Environmental Research Consortium Project H-3, submitted December 15, 2002; http://www.harc.edu/harc/projects/airquality/Projects/Status/H3.aspx.

Aw, J. and M. J. Kleeman, 2003. Evaluating the First-order Effect of Intraannual Temperature Variability on Urban Air Pollution. *J. Geophys. Res.*, 108 (D12): 4365, doi:10.1029/2002JD002688.

Berkowitz, C., T. Jobson, G. Jiang, C. Spicer and P. Doskey, 2004. Chemical and Meteorological Characteristics Associated with Rapid Increases of Ozone in Houston, Texas. *J. Geophys. Res.*, 109, D10307, doi:10.1029/2003JD004141.

Byun, D.W., S. Kim, B. Czader, D. Nowak, S.Stetson, and M. Estes, 2004. Estimation of Biogenic Emissions with Satellite-derived Land Use and Land Cover Data for Air Quality Modeling of the Houston-galveston Ozone Nonattainment Area, submitted to Environmental Manager, 2004. (Appendix G.2)

Cantu, G., 2003. *Speciation of Texas Point Source VOC Emissions for Ambient Air Quality Modeling*, Texas Commission on Environmental Quality, July, 2003. Available electronically at ftp://ftp.tnrcc.state.tx.us/pub/OEPAA/TAD/Modeling/HGAQSE/Modeling/EI/PointEI_VOC_Speciation_Report-GabrielCantu.pdf.

Carlson, T. N., J. K. Dodd, S. G. Benjamin, and J. N. Cooper, 1981. Satellite Estimation of the Surface Energy Balance, Moisture Availability and Thermal Inertia. *J. Appl. Meteor*., **20**, 67-87.

Conrad Blucher Institute Texas Coastal Observation Network. Data available at http://tcoon.cbi.tamucc.edu/TCOON/HomePage.

Daum, P., L. Kleinman, S. Springston, L. Nunnermacker, Y.-N. Lee, J. Weinstein-Lloyd, J. Zheng, and C. Berkowitz, 2004. Origin and Properties of Plumes of High Ozone Observed During the Texas 2000 Air Quality Study (TexAQS 2000), *J. Geophys. Res*. Vol. 109, D17306, doi:10.1029/2003JD004311, 2004.

ENVIRON, 2003. *User's Guide, Comprehensive Air Quality Model with Extensions v4.00.* Chapter 5, Ozone Source Apportionment Technology, pp. 5-1 to 5-37, June 2003. Available electronically at http://www.camx.com.

Eastern Research Group, 2003. Mexico National Emission Inventory, 1999. Prepared by ERG, Sacramento, CA; Acosta y Asociados, Agua Prieta, Sonora, Mexico; TransEngineering, El Paso, TX; and Alejandro Villegas-Lopez, Mexico City, Mexico, July 21, 2003. Available electronically at http://www.wrapair.org/forums/ef/docs.html, "Draft Documents."

Electric Reliability Council of Texas (ERCOT), 2003. The Texas Connection report, "Report on Existing and Potential Electric System Constraints and Needs Within the ERCOT Region," October 1, 2003.

Emery, C. Tai, E., Yarwood, G., Enhanced Meteorological Modeling and Performance Evluation for Two Texas Ozone Episodes, Final Report, 2001. Avaliable at http://www.tceq.state.tx.us/air/airquality_contracts.html#section3

Estes, M., J. Smith, J. Price, G. Cantu, D. Boyer, Z. Fang, and J. Neece, 2002. Preliminary Emission Adjustment Factors Using Automated Gas Chromatography Data. November 5, 2002. Attachment 7 to TCEQ December 2002 SIP revision (TCEQ, 2000).

Geron, C. D., A. B. Guenther, and T.E. Pierce, 1994. An Improved Model for Estimating Emissions of Volatile Organic Compounds from Forests in the Eastern United States. *J. Geophys. Res. (Atmospheres)*, **99**: 12,773-12,791.

Gillani and Wu, 2003. *Top-down emissions verification for the Houston-Galveston industrial point sources based upon TexAQS 2000 data*. HARC Contract No. H62002B, submitted to Ann Brun, June 2003.

Guenther, A., P. Zimmerman, P. Haley, R. Monson, and R. Fall, 1993. Isoprene and Monoterpene Emission Rate Variability: Model Evaluations and Sensitivity Analysis. *J. Geophys. Res.*, **98**(D7): 12,609-12,617.

Guenther, A.B. and A. Hills, 1998. Eddy Covariance Measurement of Isoprene Fluxes, *J. Geophys. Res.*, **103**(D11), June 20, 1998.

H-12 Project Team, 2004. *Draft project report: Impact of Biogenic Emissions on Ozone,* Sept 2004; Allen et al., *Impact of Biogenic Emissions on Ozone Concentrations in Southeast Texas: August and September 2000: Project H-12 Results*, Presentation to TCEQ, September 8, 2004 (Appendix G.3).

Hampden K., M. Green, V. Etyemezian, 2001. Big Bend Regional Aerosol and Visibility Observational (BRAVO) Study Emissions Inventory, prepared by Desert Research Institute for BRAVO Technical Steering Committee, November 16, 2001. Mexico Emissions Inventory excerpt available electronically at ftp://ftp.tnrcc.state.tx.us/pub/OEPAA/TAD/Modeling/HGAQSE /Modeling/Doc/TSD_PHASE1/attachment3_9-DRI_mexico_ei.pdf.

Jiang, G., J. Fast, 2004. Modeling the Effects of VOC and NO_X Emission Sources on Ozone Formation in Houston During the TexAQS 2000 Field Campaign. *Atmos. Environ.* 38 (2004) 5071-5085.

Karl et al., 2003. Use of Proton-transfer-reaction Mass Spectrometry to Characterize Volatile Organic Compound Sources at the La Porte Super Site During the Texas Air Quality Study 2000. J. Geophys. Res. 108(D16), 4508.

Korc et al., 1995. *Use of PAMS data to evaluate the Texas COAST emission inventory*. Final Report, by Marcelo E. Korc, Chris Jones, Lyle Chinkin, Hilary Main, Paul Roberts of Sonoma Technology, Inc. and Charles Blanchard of ENVAIR. Prepared for USEPA, December 1995.

Lei, W., R. Zhang, X. Tie and P. Hess, 2004. Chemical Characterization of Ozone Formation in the Houston-galveston Area: a Chemical Transport Model Study. *J. Geophys. Res*., Vol. 109, D12301, doi:10.1029/2003JD004219.

McNider, R., A. Song, D. Casey, P. Wetzel, W. Crosson, and R. Rabin, 1994. Toward a Dynamic-thermodynamic Assimilation of Satellite Surface Temperature in Numerical Atmospheric Models. *Mon. Wea. Rev.*, **122**, 2784-2803.

National Automated Buoy Data network. Data available at http://tabs.gerg.tamu.edu/Tglo/ and at http://www.ndbc.noaa.gov/Maps/west_gulf_hist.shtml.

Natural Resource Conservation Service. Prairie View SCAN data available at http://www.wcc.nrcs.usda.gov/scan/site.pl?sitenum=2016&state=tx.

Nielsen-Gammon reports available electronically at http://www.met.tamu.edu/results:

Nielsen-Gammon, J., 2001. *Initial Modeling of the August 2000 Houston-Galveston Ozone Episode*, December, 2001.

Nielsen-Gammon, J., 2002a. *Evaluation and Comparison of Preliminary Meteorological Modeling for the August 2000 Houston-Galveston Ozone Episode*, February 5, 2002.

Nielsen-Gammon, J., 2002b. *Meteorological Modeling for the August 2000 Houston-Galveston Ozone Episode: PBL Characteristics, Nudging Procedure, and Performance Evaluation*, February 28, 2002.

Nielsen-Gammon, J., 2002c. *Application of Microwave Temperature Profiler (MTP) Data to MM5 Modeling of the August 2000 Houston-Galveston Ozone Episode*, August 30, 2002.

Nielsen-Gammon, J., 2003. *Meteorological Modeling for the August 2000 Houston-Galveston Ozone Episode: Mixing Depths in the GOES Skin Temperature Assimilation*, August 30, 2003.

Pacific Environmental Services, Inc., 2002. *Development of Source Speciation Profiles from the 2000 TCEQ Point Source Database*, prepared under subcontract to ENVIRON Corporation. Available electronically at ftp://ftp.tnrcc.state.tx.us/pub/OEPAA/TAD/Modeling/HGAQSE/Contract_Reports/EI/DevelopmentOfSourceSpeciationProfilesFrom2000PSDB.pdf.

Pinker, R.T. and I. Laszlo, 1992. Modeling Surface Solar Irradiance for Satellite Applications on a Global Scale. *J. Appl. Meteor.*, **31**: 194-211.

Pinker, R.T., J.D. Tarpley, I. Laszlo, K.E. Mitchell, P.R. Houser, E.F. Wood, J.C. Schaake, A. Robock, D. Lohmann, B.A. Cosgrove, J. Sheffield, Q. Duan, L. Luo, and R.W. Higgins, 2003. Surface Radiation Budgets in Support of the GEWEX Continental-Scale International Project (GCIP) and the GEWEX Americas Prediction Project (GAPP), including the North American Land Data Assimilation System (NLDAS) project, *J. Geophys. Res.*, **108**(D22): 8844, doi:10.1029/2002JD003301.

Pinker, R.T. et al. NOAA Solar Radiation Budget data, available at http://www.atmos.umd.edu/~srb/gcip/cgi-bin/historic.cgi?auth=no

Roberts, P., S. Brown, S. Reid, M. Buhr, T. Funk, P. Stiefer, P. Hopke, E. Kim, 2004. *Emission inventory evaluation and reconciliation in the Houston-Galveston Area*. Prepared for Houston Advanced Research Center, March 19, 2004.

Ryerson, T., M. Trainer, W. Angevine, C. Brock, R. Dissly, F. Fehsenfeld, G. Frost, P. Goldan, J. Holloway, G. Hubler, R. Jakoubek, W. Kuster, J. Neuman, D. Nicks Jr., D. Parrish, J. Roberts, D. Sueper, E. Atlas, S. Donnelly, F. Flocke, A. Fried, W. Potter, S. Schauffler, V. Stroud, A. Weinheimer, B. Wert, C. Wiedinmyer, R. Alvarez, R. Banta, L. Darby, and C. Senff, 2003. Effect of Petrochemical Industrial Emissions of Reactive Alkenes and NO_X on Tropospheric Ozone Formation in Houston, Texas. *J. Geophys. Res.*, 108(D8): 4249, doi:10.1029/2002JD003070.

Song, J., W. Vizuete, Y. Kimura, and D.T. Allen, 2004. Comparison of Observed and Modeled Isoprene Concentrations in Southeast Texas during the Texas Air Quality Study, submitted to Atmospheric Environment, 2004 (Appendix G.4).

Stoeckenius et al., 2002. *Final Report: Evaluation of MOBILE for Application to Houston, TX*. Work Assignment No. 31984-21, TNRCC Umbrella Contract No. 582-0-31984. Prepared for Texas Natural Resources Conservation Commission. Prepared by Till E. Stoeckenius, Cameron Tana, Shannon Coulter-Burke, Eva Agus of ENVIRON International Corporation. November 12, 2002.

Systems Applications International, Inc., 1995. Revised Final Draft Report, Gulf of Mexico Air Quality Study (GMAQS) prepared for Minerals Management Service. Available through http://www.mms.gov/itd/abstracts/95-38-40a.html.

Texas Commission on Environmental Quality, 2000. Revisions to the State Implementation Plan (Sip) for the Control of Ozone Air Pollution, December, 2000. Available electronically at http://www.tnrcc.state.tx.us/oprd/sips/dec2000hga.html.

Texas Commission on Environmental Quality, 2002. *Revisions to the State Implementation Plan (Sip) For the Control of Ozone Air Pollution, December, 2002*. Available electronically at http://www.tnrcc.state.tx.us/oprd/sips/dec2002hga.html.

Texas Crop Weather Program. Data available at http://cwp.tamu.edu/cgi-bin/htmlos.cgi/85342.1.1574603148050327959.

Tremback reports available electronically at http://www.harc.edu/harc/Projects/AirQuality/Projects/Status/H1.aspx:

Tremback, C., 2003a. *Final Report: MM5 Simulations for TexAQS 2000 Episode*, August 14, 2003.

Tremback, C., 2003b. *Task 3: Sensitivities to modifications of the MRF PBL scheme*, September 30, 2003.

Tremback, C., 2003c. *Task 4: Review of the TKE PBL schemes in MM5.*, September 30, 2003.

USEPA, 1991. Guideline for Regulatory Application of the Urban Airshed Model, EPA-450/4-91-013, July 1991.

Vizuete, W. et al., 2002. Effects of Temperature and Land Use on Predictions of Biogenic Emissions in Eastern Texas, USA. *Atmos. Environ*. **36**(20): 3321-3337, doi:10.1016/S1352-2310(02)00272-8.

Wert, B., M. Trainer, A. Fried, T. Ryerson, B. Henry, W. Potter, W. Angevine, E. Atlas, S. Donnelly, F. Fehsenfeld, G. Frost, P. Goldan, A. Hansel, J. Holloway, G. Hubler, W. Kuster, D. Nicks, Jr., J. Neuman, D. Parrish, S. Schauffler, J. Stutz, D. Sueper, C. Wiedinmyer and A. Wisthaler, 2003. Signatures of Terminal Alkene Oxidation in Airborne Formaldehyde Measurements During TexAQS 2000. *J. Geophys. Res*. 108(D3): 4104, doi:10.1029/2002JD002502.

Wiedinmyer, C., A. Guenther, M. Estes, I.W. Strange, G. Yarwood, and D. T. Allen, 2001. A Land Use Database and Examples of Biogenic Isoprene Emission Estimates for the State of Texas, USA. *Atmos. Environ*. **35**: 6465-6477.

Yarwood, G., T. Stoeckenius, S. Lau, 2003a. *Top-Down Evaluation of the Houston Emission Inventory using Inverse Modeling* prepared for the Houston Advanced Research Center by ENVIRON, Project No. H6E.2002, available electronically at http://www.harc.edu/harc/projects/airquality/projects/status/files/h6edraftreport.pdf.

Yarwood, G., G. Wilson, S. Shepherd, and A. Guenther, 2003b. *User's Guide to the Global Biosphere Emissions and Interactions System (GloBEIS3),* 16 July 2003. Downloaded from http://www.globeis.com.